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THE BRITISH JOURNAL OF METALS

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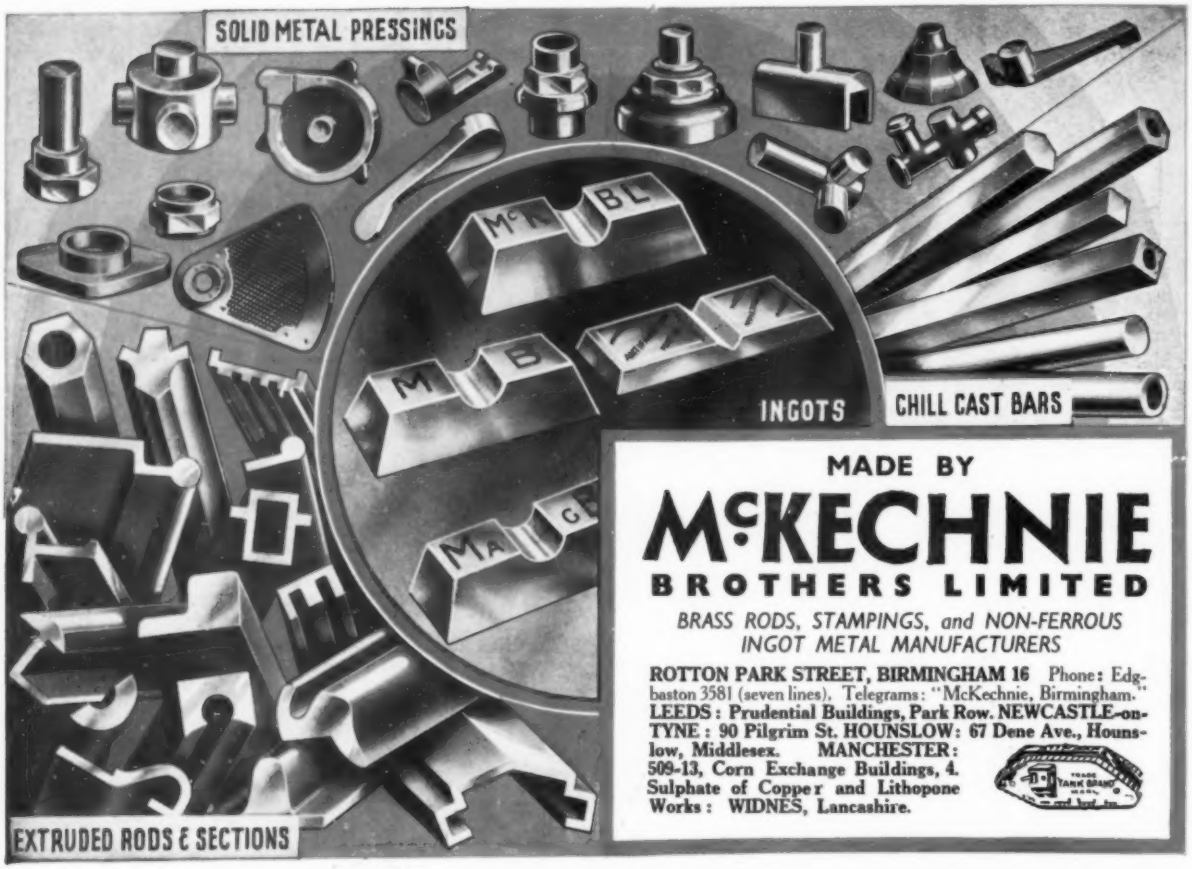

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The British Journal of Metals

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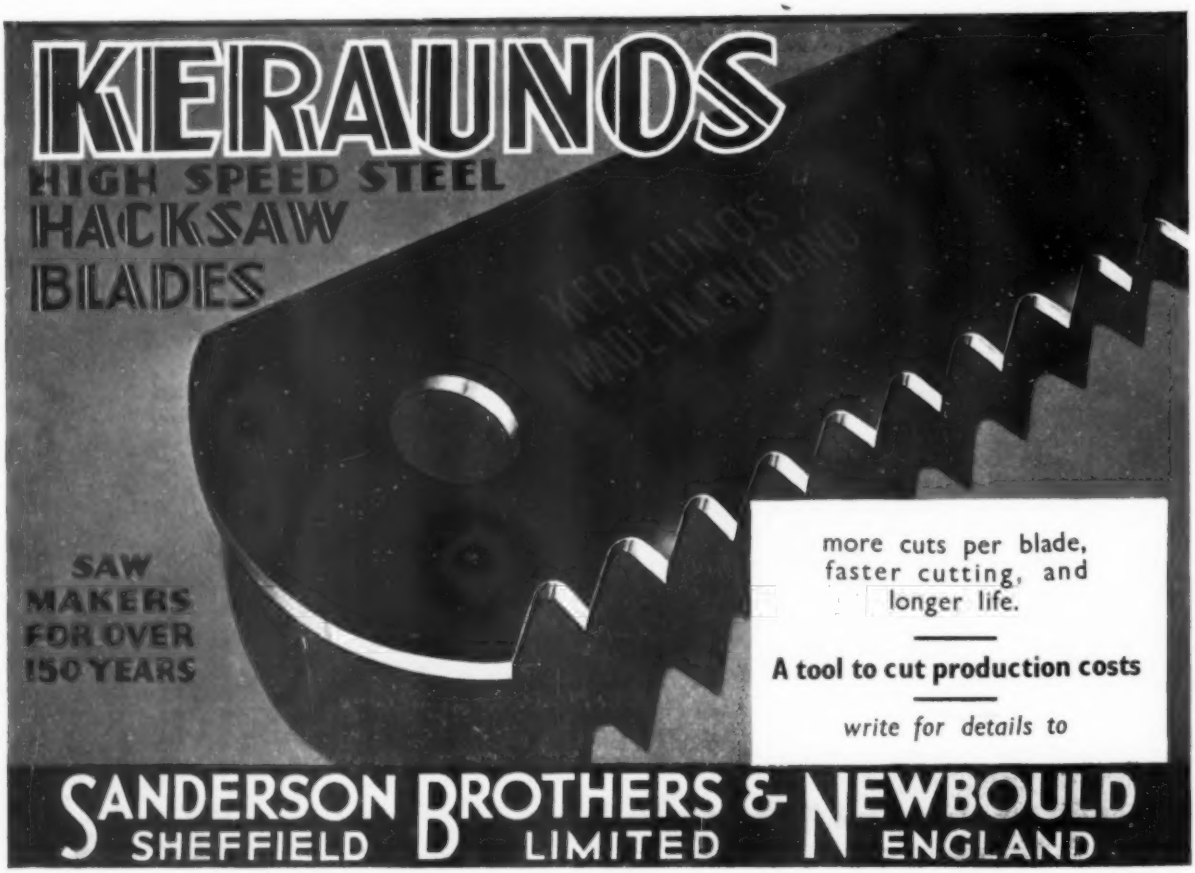
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JANUARY, 1940. VOL. XXI, No. 123.

A Modern Cast Iron—Meehanite

By E. M. Currie

Considerable study and research has been devoted to the manufacture of improved cast irons in an effort to enhance its properties. The results have led to remarkable achievements, and in this article one of the outstanding advances is briefly described. It deals with a range of cast irons in which ladle graphitisers are added to the molten metal. Some data on the properties of these cast irons is given and reference made to some applications.

DURING the past ten years, in common with practically every other industry, that dealing with cast iron has seen accelerated progress of a degree far greater than at any previous time in the long history of its use as a major metal. Considerable study and research has been devoted to the manufacture of improved cast irons in an effort to enhance its properties to combat the encroachment of plastic products, steel, and welded structures, and of the light metals. Every possible avenue of improvement has been, and is still being, explored with an intensity never before known in the field of cast iron.

Less than twenty years ago many notable people of the metallurgical world publicly predicted its almost total eclipse as a construction material, due to its unreliability and the lack of dependable data. To-day, however, the whole position is radically altered. Apart from the abundance of supplies of cast iron, constant research is lifting grey cast iron from its position of intermediate importance to a leading and scientifically dependable article of every-day commerce and industry.

From the metallurgical point of view, grey cast iron is neither a refined nor an unrefined product, it lies half way, and differs from true alloys of ferrous base by the presence of suspended graphite particles when in the molten state. It is in the control of structure make-up that the modern metallurgical development in improvement of cast iron lies.

This has been approached in many ways—by the use of many other metals as alloy additions, by superheating, by heat-treatment, by modified melting practices and variations of cooling rates, and literally hundreds of variations of moulding and casting technique. The results of all these different methods to obtain the same object are seen in the many examples of improved cast irons to-day, and although progress has been hampered somewhat by the necessity for retaining the identity of "common cast iron" and its economic advantages over other metals, nevertheless remarkable achievements in the production of a truly dependable and predictable material, with vastly improved physical characteristics, has evolved. One of the outstanding advances in this direction has been that following on the use of ladle graphitisers, the first patent in connection with which was taken out by Meehan. Progress in this direction resulted in the development of the Meehanite process.

To the engineer and designer, cast iron is regarded as a "brittle" material which does not possess true elastic properties—that is, it does not give a straight line relation between stress and strain in a tensile test. Such a thought does not hold good to-day. The modern cast iron can be so made that its dependability and properties are accurately known and are reliable; it is a cast iron that is not brittle and which can easily be modified to suit exactly each and every service condition demanded of it.

Owing to the difficulty and special equipment necessary, accurate measures of elastic constants are not easily or cheaply made, and therefore the metallurgist has been content to allow the designer to work from the comparatively inaccurate formulas obtained from simple transverse tests. Modulus values from such methods mean little. Adamson and Bell, in the Carnegie Memoirs (1927) have shown that common grey iron bars, 1 in. × 1 in., tested

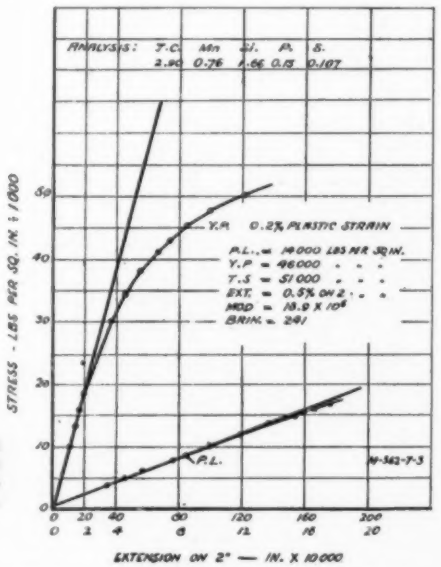

Fig. 1.—Tension test curves on Meehanite Metal as-cast.

transversely on a 36-in. span, and computed on a deflection basis, will give a modulus value of 11,500,000 lb. per sq. in., whereas the same bar on a 12-in. span records 6,500,000 lb. per sq. in.

Obviously, therefore, apart from explanations on analytical grounds, support deflection, unequal loading, etc., to the engineer who must work with such material constants, uncertainty results and the lowest figure will be taken, which may actually mean that he will work with a safety factor anywhere between 10 and 100 times what may be the true figure, whereas for steel the usual figure of 30×10^6 lb. per sq. in. is accepted and used.

In these days, reliance and knowledge on the material used is absolutely necessary. It is noteworthy that irons made with graphitising additions are now widely made and used, and have a density and strength which makes them

very attractive to the engineer and designer. The process of manufacture consists in preparing a cast iron whose composition will give practically a white fracture when cast into the sectional thickness intended, and converting this into a dense grey iron by means of a carefully calculated ladle addition to the molten metal. This results in a dense grey iron, and by means of this process the strongest cast irons in the "as-cast" condition are made, having a tensile strength up to as much as 30 tons per sq. in. Development in the process has resulted in a wide range of cast irons, and since the ladle additions may be used in conjunction with alloy additions, the scope is greatly increased. Some data on the properties of cast irons in this range will be of interest.

Figs. 1 and 2 show correctly made elastic limit curves of Meehanite process "A" iron, as-cast and heat-treated. The modulus of the as-cast "A" metal is 19,000,000 lb. per sq. in., and for the heat-treated process is 26,000,000 lb. per sq. in.

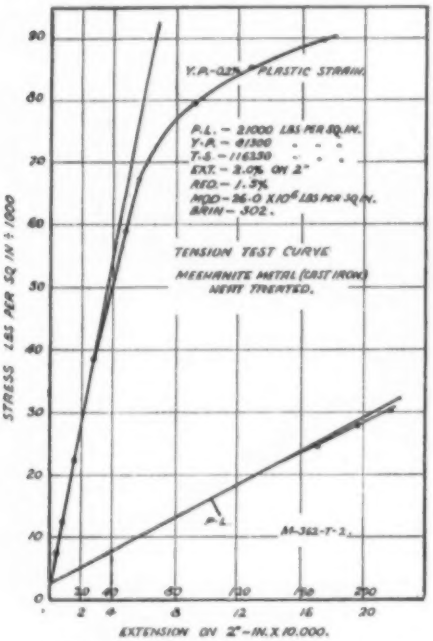
Y.P.-02% PLASTIC STRAIN.
P.L. - 21000 LBS PER SQ.IN.
Y.P. - 61300 " " "
T.S. - 116350 " " "
EXT. - 3.0% ON 2"
RED. - 1.5%
MOD - 26.0 X10⁶ LBS PER SQ.IN.
BRIN - 302.
TENSION TEST CURVE
MEEHANITE METAL (CAST IRON)
HEAT TREATED.
STRESS LBS PER SQ IN ÷ 1000
EXTENSION ON 2"-IN. X 10,000.

Fig. 2.—Tension test curves on heat-treated Meehanite Metal.

Dealing with the question of "brittleness," this word is in the ordinary sense opposed to "toughness." When applied within the confined limits of physical testing, these terms can determine the degree of deformation which occurs at rupture. A really fragile material will break with very little or no deformation, while conversely the greater the toughness the more it deforms.

If the fracture produced with steel is compared with cast iron, then by comparison cast iron is said to be brittle, as there is no "necking" of the tensile test-piece as there would be with steel. On the other hand, a close study of stress-strain diagrams of both steel and cast iron will show that while the initial slope of the curve in the case of steel is steeper than that of cast iron, because of its higher modulus of elasticity, it will be seen in both curves that a degree of plastic deformation occurs at the point where the curve leaves the original straight-line relationship between stress and strain. In truly "brittle" materials, such as glass or porcelain, there is no plastic deformation shown on stress-strain diagrams, therefore there is a greater analogy between cast iron and steel than between cast iron and truly brittle materials.

Apart from the foregoing, X-ray studies of the atomic structure show that cast iron and steel present *ordered* crystalline formation of the atoms in network formation. With an ordered arrangement, slip is possible along cleavage planes giving plastic deformation. Truly brittle materials do not differ from liquids in their atoms and take no ordered form of dispersion. Thus, it merely becomes a question of degree, and cast iron thus approaches steel more nearly than it does brittle materials. Its matrix is no different from steel except that it is broken up by microscopic inclusions of graphite.

Plastic deformation disappears when mechanical stress is no longer fixed, but becomes alternating. With failure due to fatigue or repeated shock, all materials exhibit a brittle fracture, and as the most frequent case in actual service is the question of fracture due to fatigue, the fact that a cast iron will show a brittle appearance under static stress is absolutely unimportant. Therefore, from the appearance of this fracture, no forecast can be made of the behaviour of a material under alternating stresses. The damping capacity of a material cannot be calculated from the amount of elongation or reduction of area on a tensile test-bar.

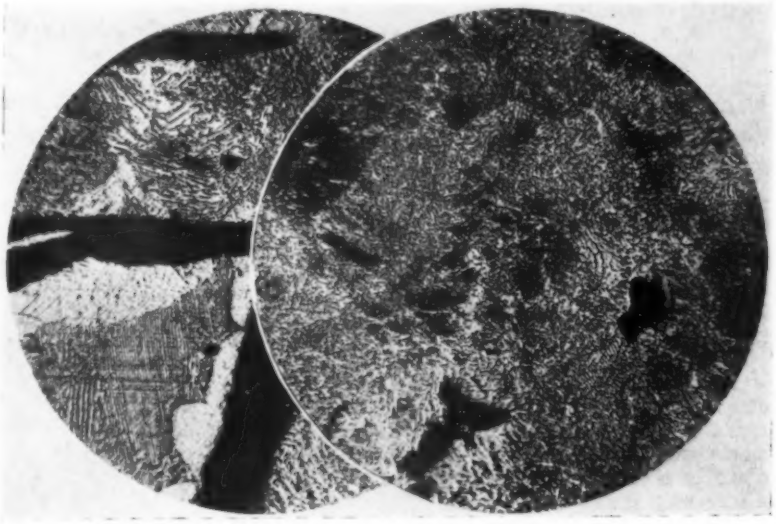

Fig. 3.—Structure of grey cast iron containing 0.47% combined carbon. × 1,000.

Fig. 4.—Structure of Meehanite Metal as-cast. × 1,000.

Reproduced half-size.

It is known that cast iron has a low "notch sensitivity" and a higher damping capacity than steel, which makes it of considerable importance in the case of alternating stresses. It is on the basis of this knowledge that the application of high-duty cast irons to such service as crankshafts has been so successful and striking.

Designers in general consistently underestimate what they can demand of a modern high-duty iron casting. The ease with which cast iron can be cast to shapes to give good mechanical strengths is usually forgotten or ignored, and machines are built up too often in real ignorance of the physical properties of the actual metal used.

Continued research and study into practically all the physical properties of cast iron has resulted to-day in a type of high-duty cast iron of known and predictable properties. Meehanite metal is produced in five main engineering grades, each of which is capable of infinite and controlled modifications to meet specific services in the heat resistance, wear resistance, and corrosion resistant fields.

This cast iron is made in the cupola, electric, air or oil-fired furnaces, and makes use of considerable scrap steel. By the technique of manufacture and the control of the physical constitution of the carbides, it is possible to control graphitisation to form and quantity at will. The essential difference between ordinary cast iron and Meehanite is that in the former the graphite is of the primary variety, while in the latter it is of the secondary variety. Figs. 3 and 4 show this quite clearly together with the

essential difference in the matrix structure. This structural feature explains the remarkable toughness of cast irons produced by this process, as measured by repeated impact, single impact, and rotary fatigue tests.

The presence of coarse flakes of graphite and the instability of the carbide in ordinary soft grey irons are responsible for the uncertain results obtained by the heat-treatment or annealing of cast irons in order to obtain greater strength, hardness, ductility or machinability. Decomposition of carbide is bound to occur on heating before quenching or for controlled annealing, therefore the degree to which graphitisation is carried out must be critically and accurately done if the required results are to be achieved with certainty. Little or no distortion is apparent when treatment is carried out correctly. Hardnesses from 200 up to 600 may be obtained. Tensile strengths up to 30 tons per sq. in., Charpy impact figure of 12 ft.-lb., and repeated impact of 12,000 blows as against semi-steel of 200 and alloy cast iron of 500 blows.

The normal minimum guaranteed general engineering physical properties of Meehanite are given in Table I.

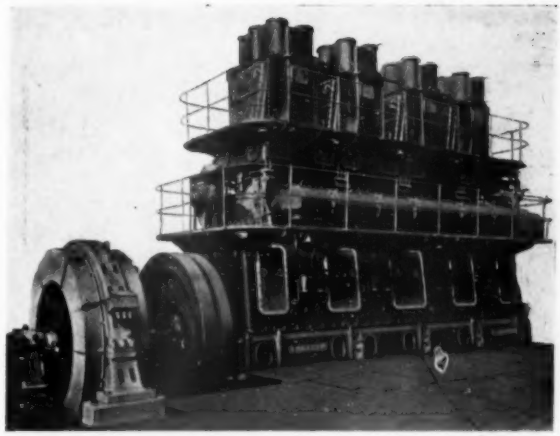

Fig. 5.—Large Fullager type Diesel engine.

TABLE I.
GENERAL ENGINEERING SPECIFICATIONS.

Meehanite Process.	Tensile Tons/Sq. In.	Transverse 1·25 in. Bar Between 12 in. Centres.	Deflection, Inches.	Brinell Hardness No.	Compression Strength, Tons/Sq. In.	Modulus of Elasticity.	Fatigue Strength, Tons/Sq. In.	Specific Gravity.	Min. Section for Small Castings.
"A"	22·5 — 33·5 Heat-treated	2·2 to 3·2	0·15 to 0·20	196–500 — to 600 Heat-treated	79	21,000,000	10 — 12·5 Heat-treated	7·43	$\frac{3}{8}$ in.
"B"	18·5 — 27·5 Heat-treated	2·3	0·18	196–450 — to 500 Heat-treated	72	19,000,000	8·7 — 10·5 Heat-treated	7·37	$\frac{1}{4}$ in.
"C"	17·0	2·0	0·17	196–450	68	17,000,000	8	7·25	$\frac{3}{16}$ in.
"D"	15·5	1·8	0·17	175–450	61	15,000,000	7	7·13	$\frac{1}{8}$ in.
"E"	13·5	1·7	0·16	140–450	54	12,000,000	6·2	7·02	Any Size
Cast Iron and Semi-Steel	9·0 to 13·0	1·1 to 1·6	0·10 to 0·15	140–450	35 to 50	7,000,000	4·0 to 6·0	7·02	—
Cast Steel	28·0	2·3	0·20	165	43	29,000,000	12·5	7·90	—

Another property of cast iron of importance to engineers is the effect of mass influence on strength. Openness of grain at change of section—for example, root of gear teeth—means that each square inch of cross-section of the metal is not carrying its full load and therefore is a danger spot in case of sudden overload or stress, causing failure. Meehanite foundries regularly make tests on bars of various diameters, and the average results on one such test is given in Table II.

TABLE II.
TENSILE STRENGTH IN RELATION TO SECTION THICKNESS.

Section of Casting Tested, Inches.	Tensile—Tons per Sq. Inch.	
	Grey Cast Iron.	Meehanite "A."
0·75	12·3	—
1·25	11·5	23·9
2·00	8·2	24·2
3·00	6·8	23·7
4·00	—	22·7
6·00	—	21·2

Applications of Meehanite Metal

Meehanite castings are to-day applied literally to practically all forms of service where cast iron has been used, and in many cases have replaced steel castings.

In gears, the accuracy of this metal, its quiet and smooth operation due to absence of internal strain, uniformity of structure and density throughout all sections have produced exceptional results. A 350-ton printing press, built by the French firm of Edward Lambert, is an example in which such gears operate. Paper travels through this machine

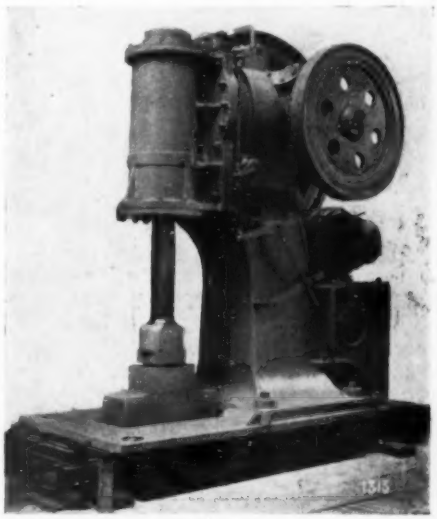

Fig. 6.—Modern type of steam hammer.

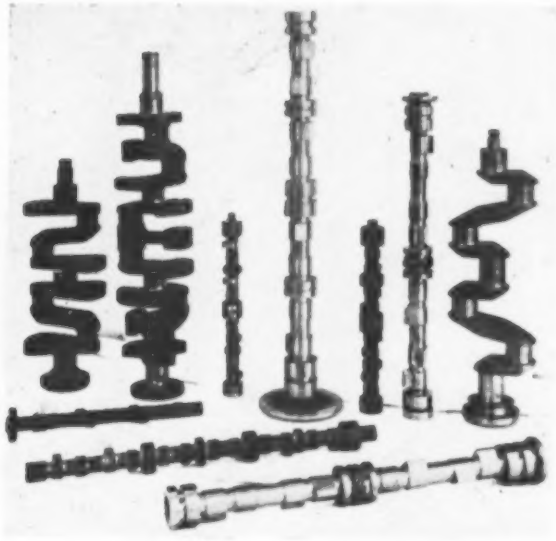

Fig. 7.—Group of crank and camshafts cast in Meehanite.

at the rate of 212 miles per hour, producing 380,000 eight-page issues every hour. The Diesel engine shown in Fig. 5, claimed to be the largest stationary type made in this country, having a horse-power of 3,500, and known as a Fullager type Diesel engine, is another striking example of the application of this cast iron. The steam hammer, illustrated in Fig. 6, is an example in which all castings, including the dies, were made in Meehanite. The use of cast crank and camshafts has made great progress in recent years, and the group of castings in Fig. 7 illustrates the application of Meehanite for work of this type.

In the machine-tool field many thousands of tons of Meehanite have been used in building the different types now available during the past few years. A typical machine tool, involving castings of this type, is shown in Fig. 8. Power transmission through metal which must be capable of bearing the load without wear, deflection or vibration, and maintenance of accurate dimensions after machining, without the necessity for lengthy ageing or annealing, have made Meehanite of real value and helpfulness in this industry.

Dies are produced for practically all purposes and industries, and a recent technique has developed the cast-to-form die in one piece, eliminating costly building up

Fig. 9.—Large press dies cast to shape in Meehanite.

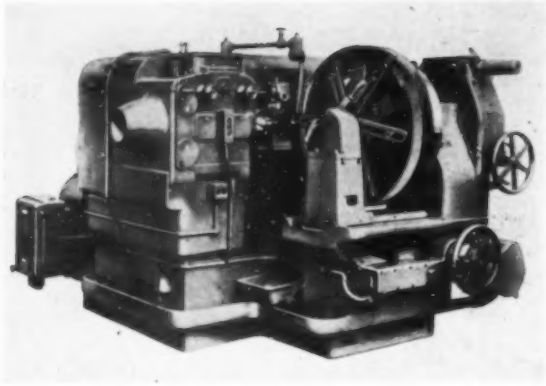

Fig. 8.—A gear-shaping machine representing a typical machine tool.

and assembly constructions. Such a press die is illustrated in Fig. 9. Electron diffraction studies have shown that, in dies, the development of a high molecular mobility under extreme working pressures produces a surface that takes a high polish quickly and at the same time creates an unusual surface hardness, which reduces or eliminates wear during the working life of the die. Also, as the graphite is uniformly distributed throughout the metal in a uniform and homogeneous manner, the great surface pressure exerted on it by the engaged parts results in a fine surface smear of graphite, which acts as a lubricant and reduces scoring and seizing. A recent result on a Meehanite die-pressing tube forms in stainless steel gave a run of over 10,000 before the die needed redressing. The manufacturer stated that his former cast-iron dies gave only 200 pressings before redressing. The rigidity of structure is such that the metal will not flow under pressure or flatten out, as is common with some types of steel dies.

Aluminium Alloy Crankcase Forgings (Softened)

New D.T.D. Specification 246a

THIS material specification covers the alloy known as Hiduminium RR 56 NS. The usual stipulations regarding the constituents of the alloy are made. The chemical composition shall be :—Copper, not less than 1·5, nor more than 2·5% ; nickel, not less than 0·5, nor more than 1·5% ; magnesium, not less than 0·6, nor more than 1·2% ; iron, not less than 0·8, nor more than 1·5% ; titanium, not more than 0·12% ; silicon, not more than 1·0% ; aluminium, the remainder ; and a complete analysis of every cast shall be supplied to the inspector. Unless otherwise specified, the forgings shall be supplied in the heat-treated condition, forgings and test samples being heat-treated together. The heat-treatment consists of heating for 2 hours at 520 ± 5° C., followed by air-cooling, and then heated at 200 ± 5° C. for 2–5 hours and finally air-cooled.

The test samples must be of the same cast as the forging itself, and may be forged down from a similar ingot, provided the reduction in section is not more than the proportionate reduction from the original forging ingot to the ruling thickness of the forging.

The mechanical properties of the material shall be as follows :—0·1% proof stress, not less than 7·0 tons per sq. in. ; maximum stress, not less than 16·0 tons per sq. in. ; elongation, not less than 16% ; Brinell hardness number, not more than 85 (70–80).

A hardness test shall be carried out on each forging by an improved method within seven days of heat-treatment. The hardness number obtained must comply with the value specified above.

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Keep Trade Channels Open

WE are told at almost daily intervals by members of the Government, and others who have some authority, that the primary concern of Britain is the prosecution of the war to a successful conclusion. There must be very few people in this country who are not in complete agreement that the energy of the nation should be unceasingly directed to this end; in fact, it is doubtful whether the people of this country have ever supported the Government so wholeheartedly as in this cause against aggression. But while the organisation of industry and man-power to this end should be the primary concern of the Government, the organisation should not be such as to exclude facilities for trade.

It is obvious that in war-time the Government cannot avoid interfering with the normal peaceful activities of industry. The introduction of necessary controls and permits, operated by Government officials, seriously hinder industry and increase the difficulties normally associated with trade, particularly as the rules on which these officials work change frequently to meet current exigencies. It is generally recognised that industrial progress during a war is directed into artificial channels and the supplies of raw materials used primarily for the fighting services. The products are mainly for destructive purposes, and from a trading point of view represent so much waste. Although this work for destruction is imperative under present conditions, it is necessary to give some attention to work of construction, to make greater use of the man-power available, and to make an effort to reduce the gap between imports and exports so that there will be a nearer approach to equilibrium.

The cost of the war is increasing, and will continue to increase, largely because greater amounts of food and raw materials are imported and must be paid for. Normally, imports are paid for by exports and services, but the gap existing between imports and exports has widened with a substantial balance against this country. The burden of taxation to meet the cost of war is already heavy and threatens to be heavier, but every pound's worth of products sold overseas compensates for an equal value of imports, and tends to reduce the weight of taxation. Apart from minor considerations, however, it is just as vital in war as in peace that we meet our obligations for imports by exports. Production for the fighting forces, and to meet the demands for the home markets, is not nearly so difficult as production for export, yet some degree of simplification to facilitate export trade is more necessary to-day than for home requirements. At least some form of priority should be instituted to enable manufacturers to obtain supplies of essential raw materials for products to be exported, which should have preference over supplies for the home trade. It should be remembered that nearly a million-and-a-half people are unemployed, which indicates that the energy of the nation is not yet absorbed to its economic limit.

Unnecessary expenditure by the Government, no less than by the individual, should be guarded against. It is difficult to appreciate, for instance, the building of huge factories, at great expense, for the production of small, engineering components which could be made as well in thousands of the smaller engineering shops in the industrial areas. These small shops already have trained men and machines available, and it would be a simple matter to organise areas with a central depot for the inspection and supply of raw materials to the various shops and the checking and inspection of finished products from them.

It is very gratifying to note the efforts of the Government to reach trade agreements with many European countries. This is a great advance on the Great War, when the first trade agreement was not made until the end of 1916. On this occasion, after four months of war, the Anglo-Swedish agreement is operating amicably, and it is confidently expected that four or five further war-trade agreements will be signed in the next few weeks. Arrangements with Belgium are completed in all but minor details, and trade delegations from several other countries have nearly finished their work. In Spain considerable progress is being made, and the British trade delegation is expected to return home shortly with an agreement. The Dutch negotiations are stated by authoritative sources to be continuing satisfactorily. The Anglo-Italian Committee, sitting in Rome, is making progress, and a report may be expected shortly.

The attainment of economic agreement between this country and the several neutral European countries will have considerable influence on export trade, since the object of the agreements is to maintain the highest volume of trade possible under war conditions. France and Belgium have already signed such an agreement. It is obvious that Britain and France should give all possible help to those neutrals that lie closest to Germany and who suffer most from the inconveniences of our contraband control. It is in their interest, as well as ours, that we should keep up our exports to them and that larger quantities of their products should be imported by Britain.

It is significant that Britain and France should take action in developing these economic associations between themselves and the European neutrals. Although conditions are such that they must conserve their resources and spend as little as possible abroad, Britain and France realise that, in the interests of the cause for which they are fighting, they must keep open the old forms of trade. The agreements also indicate that the economic unity likely to bring France and Britain more closely together will not be exclusive.

In his message to Congress, President Roosevelt pointed to the example of the twenty-one American Republics in displaying unanimity of ideals in their practical relationships, and hoped that what was being done in the Americas could be done in other continents. He urged that the present method of American trade agreements should be extended as an indispensable part of the foundation of any stable and desirable peace. It would be absurd at present to even hazard a guess at what the future may bring, but the Anglo-French agreement might be the beginning of ties between States which peace may bring to Europe. How near we are to putting the Federal idea into practice it is impossible to say, though remarkable progress has been made with Britain and France in promoting the common interests of war; the completeness with which they achieve economic unity and the manner in which they maintain trading relations with other countries during the war will, however, have a considerable influence on the form of the new Europe when peace has been restored.

Progress in Electric Plant and Equipment

IN spite of the political situation during the past year the electrical industry has remained in a healthy position, and the leading firms have continued to show steady progress both in contracts received and in technical development. There has been considerable demand for heavy electrical plant, and important orders have been received for large turbo-alternators, transformers and switchgear. In industrial plant there has been a continued demand for electric winders and rolling-mill equipment, and valuable orders have been received.

It is particularly gratifying, in view of the tremendous importance of export business at the present time, that there has been great activity in work for overseas. G.E.C.'s overseas trade, for instance, fell little below that of the previous year, which constituted a record. The policy of extending overseas markets is proceeding with vigour, many important contracts having in fact been received since the outbreak of hostilities. Several large turbo-alternators have been in course of construction during the year by the G.E.C.; three new contracts, of particular interest as being repeat orders, included a 40,000-k.v.a., 3,000-r.p.m. set, the third of this size and the tenth in all for Johannesburg municipality, and a 17,000-kw. set which represents the fifth of this output for Adelaide.

The aggregate capacity of new turbo-generating plant ordered during the year has constituted a record for the Metropolitan-Vickers Electrical Company Ltd. No fewer than 10 sets of 30,000 kw. or over have been put into manufacture, together with other units of 25,000 kw., 24,000 kw., and 15,000 kw. Orders for smaller plant have been equally satisfactory, which included two units for the Broken Hill Mines, South Africa. During the year considerable progress has been made on the plant for the Brimsdown "B" Station of the North Metropolitan Power Station Company, and the Battersea Station of the London Power Company.

Contracts received by the B.T.H. Company during the year also include repeat orders for 30,000 kw., 3,000-r.p.m. machines, the fourth 12,500-kw. set for an important railway, and two further 15,000-kw. units. Noteworthy among the orders for export include a second 18,750-kw. unit for Brisbane City Council, and a 25,000-kw. machine for the Union of South Africa Electricity Supply Commission.

Electric Furnace Equipment

The increased need for special and alloy steels occasioned by the present armaments programmes has brought most induction-furnace equipments into full-time working, and demands for further installations have been met, so that this year the output in this class of apparatus has been fully maintained by the Metrovick Company. The provision of equipment to allow of the full output of the furnace irrespective of the lining wear is now possible. Normally, the wear of the refractory lining causes changes in the furnace characteristics, which make it impossible to maintain the same melting time throughout the lining life. With large furnaces the difference in output between new and worn lining conditions may be considerable, and thus may upset a works programme. To overcome this, a larger generator and condenser bank are installed, capable of sustaining the rated power output over a wide voltage range.

During the year the value of earth leakage protection apparatus has been amply demonstrated. On a furnace of large capacity the earth leakage relay tripped during furnace operation when no fault was apparent. The charge was removed and the lining taken out carefully, when a small tongue of steel was found which had penetrated the lining to within a short distance of the coil. Such a tongue of metal might have been the precursor of a serious break-through of metal to the coil resulting in considerable damage, whereas the leakage relay gave warning, so that no damage occurred.

Rolling-mill Drives

A significant feature of the electrical work of the past year is the large number of orders put in hand for rolling-mill drives, for both ferrous and non-ferrous equipment. At one plant Metropolitan-Vickers has installed a reversing non-ferrous mill comprising an 860-h.p. (R.M.S.), 2,150-h.p., peak 0/330/400-r.p.m. d.c. mill motor with M.G. set and Ward Leonard control and several additional non-reversing drives, ranging from 120 h.p. to 330 h.p., complete with H.T. and L.T. switchgear, distribution switchboards and cables. A particular point of interest in the reversing mill equipment is the synchronising of the motors driving the working rollers back and front of the mill with the mill itself.

For steel works drives orders for several large reversing mill equipments have been received by the same company. One of these comprises a 36-in. reversing bar-mill drive consisting of a 4,000-h.p. (R.M.S.), 13,430-h.p., peak ± 0/55/140-r.p.m. d.c. mill motor supplied from a 3,200-kw. flywheel M.G. set driven by a 3,300-volt, three-phase, 50-cycle induction motor. Another drive for a 20-in. reversing-bar mill for export comprises a 1,250 h.p. (R.M.S.), 3,750-h.p., peak ± 0/45/100-r.p.m. d.c. mill motor controlled on the Ward Leonard principle and supplied from a 1,040-kw. flywheel motor-generator set driven by an 11,000-volt, three-phase, 50-cycle induction motor. For the same customer a 1,000-h.p. (R.M.S.), 3,000-h.p., peak 200/360-r.p.m. mill motor supplied from an 810-kw. M.G. set driven by a synchronous induction motor has also been ordered for driving a 12-in. merchant mill.

A large amount of plant and equipment for the iron and steel industry has been constructed during the year by General Electric Company Ltd., one of the most important contracts being that for John Summers and Sons, Ltd. Some of the most interesting drives are for the slabbing-mill auxiliaries, which consist of the tables, manipulator, screw-down and shear drives; these operate on the three-field generator system with power supplied from two synchronous motor generator sets, an individual generator being provided for each of the drives. The shear drive is one of the largest of its type in this country. It operates in such a manner that the whole duty cycle, consisting of acceleration, cutting, deceleration and stopping at a pre-determined fixed position, is completed in 10 secs.

Among the many tube-mill installations supplied and put into operation during the year, an interesting installation is that by Metropolitan-Vickers, in connection with a tube-sizing mill of the reversing type. The mill is driven by a 250-h.p. (R.M.S.), 500-h.p., peak 0/750 r.p.m. d.c. mill motor through a reduction gear, the motor being supplied from a motor generator set driven by a 360-h.p. slipring induction motor and controlled on the Ward Leonard principle. The live rollers on the ingoing and outgoing side of the mill are required to accelerate, decelerate and run in exact synchronism with the mill. To achieve this object the live rollers are driven by direct-coupled 230-volt d.c. motors connected to the generator supplying the main mill motor, so that every movement of the Ward Leonard controller which produces a change in speed of the mill motor produces a proportional change in speed of the live-roll motors. For reasons of design the mill motor was built for 460 volts d.c. maximum, but since this voltage is too high to obtain a satisfactory design for the small live-roll motors, a small negative booster is connected in series with the supply from the main generator to the live roll motors causing the voltage applied to the latter to be always 50% of the main motor and generator voltage.

It has only been possible here to refer briefly to a few industrial equipments ordered, and in some cases put into operation during the year, but sufficient to indicate that in these troublesome times the electrical industry is maintaining progress and keeping its home and overseas trade in a healthy condition.

Industrial Management and Production Control

Part XIII.—The Works-Economics Department

By F. L. Meyenberg

In this, the last article of the series, the author deals with a special department which is concerned with production research, based on organisation, work and time, and costing-studies, reported in a form convenient for the guidance of the works manager and departmental managers. The function of this department is described and its organisation discussed, special reference being made to the operation of such a department in a South African Iron and Steelworks plant.

LOOKING back on this series of articles, of which the present one is the conclusion, I can imagine that some readers may say: "They sound quite well, but who shall do the work connected with so many of the proposed measures? Who shall carry out these jobs in the spirit of co-operation so often rightly emphasised, and who shall take care of the economical viewpoints and avoid obnoxious exaggeration? We would not be satisfied by the answer that it would be the duty of the man at the top; for he has too much to do in current business affairs, and in keeping a general survey of the whole position of the undertaking, to be able to deal with the details these problems require; we would also reject as a mere phrase the answer that he should only create the necessary *corps d'esprit* and leave everything else to his direct subordinates."

These objections are certainly justified; it is a full-time job, which here is only indicated in rough outline, at least if the works concerned have grown up from relatively small beginnings as metallurgical works nearly always do. It is the work of production research, based on organisation-, work and time- and costing-studies, combined in the correct mixture, and leading to conclusions which should be the guide for future management by works and departmental managers. The answer to our foregoing question can only be that a special department should be created, which must be trusted with this difficult, but highly interesting task, and which in analogy to the generally accepted expression "national economics" we may call the "works-economics department"; just as a Ministry of Economics would supervise the nation's economic life, so this department would fulfil the same function for the works, taking the word "economics" in current sense of the compromise of the technical, economic and psychological considerations.

But before we turn to a more explicit description how this function can be be fulfilled by the works-economics department and therewith show the proper contents of this last article, a remark may be allowed in connection with the term "costing-studies," which is mentioned for the first time in this series. The reader will have perceived that we have had studies of this kind in mind without expressly mentioning their name and explaining in detail their nature and method.

He may, perhaps, even consider that a regrettable defect. May I answer that this omission was made intentionally, certainly not because I have underestimated the importance of such studies; on the contrary, the omission was made because it would not have been possible to do justice to these problems in the scope of these articles without at least doubling their extent.

The Works-Economics Department

With regard to the desire to give not only theoretical explanations, but to show an example taken from actual practice how the work is done, the following is an extract of a publication* on the organisation of a South African iron and steelworks, where such a department was in existence, even before the newly built plant had begun to work, and could exhibit valuable success at the time of the publication—i.e., more than two years after the starting of production.

The iron and steel works in question, the South African Iron and Steel Industrial Corporation, Ltd. (Iscor.), is built up on a raw material basis in the possession of the company, and is composed of ore and dolomite mines, a coal-washery plant, coke ovens and a by-product plant, blast furnaces, a steel melting shop, a lime and dolomite burning plant, a cogging and finishing mill, a sheet mill, a foundry, and the necessary power station and auxiliary shops.

The duties of the works economics department had been fixed in the beginning by a written programme, and this has proved, in general, appropriate under the working conditions, so that it can to some extent be taken as a description of its actual work.

The position of the department in the organisation is characterised by the fact that it depends directly upon the man at the top and that it forms a connecting link between the individual shops mutually, and these shops and the management on the one hand, and the technical side of the works and the costing department on the other hand.

From this position the main duties result:—

1. The works-economics department has a decisive word concerning the construction of the costing department, in order to avoid, from the beginning, the usual discrepancies which may arise from the different interests of the technical and commercial side of the undertaking on the results of the cost department. This construction has been built up in close connection with the works accountancy department, and it has been determined that future changes could be only made in close co-operation of both.

The works-economics department has further to take care of:—

2. Construction and future development of the general works organisation.

3. Time studies as assistance for production control, rate-fixing or costing purposes.

4. The planning system from the costing as well as from the production point of view.

5. The economics of material of any kind.

6. Cost and production statistics.

7. Special investigations of any kind believed to be desirable for the improvement of the economy of the undertaking.

All these duties are carried out on behalf of the managing director and general manager, and any demands of the individual departments must first be sanctioned by the management. Fuel department and test-house are separated sections, but work together with the works-economics department where necessary.

*See *Archiv fur das Eisenhuttenwesen*, 10/1936/37, No, 3, pp, 119/129.

The Organisation of the Works-Economic Department

The staff of this department has intentionally been kept as low as possible. During the first two years of production it comprised the manager of the department, three specially trained engineers as assistants, and a secretary for administrative work and correspondence. Help was given, if necessary, for extensive investigations—e.g., time studies on a plant composed of several machines, by persons borrowed from other departments, and by apprentices training for the position of production engineer.

It may seem to be incredible that such a small staff should be able to carry out the duties enumerated above ; but it should not be overlooked that it is not the job of the works-economics department to do the routine work covered by the seven headings given, but on behalf of the general manager, to determine how this work should be done, and to smooth out and settle difficulties which may arise.

Fundamental rules have been made to guide members of the staff of the works-economics department in carrying out this difficult and responsible job—e.g., the manager of any department concerned in an investigation should be informed in advance about the kind and extent of this investigation, nothing should be done in his department during the investigation without his knowledge, and the final report should be discussed with him in detail, before it is issued to the general manager, etc. ; but much must be left to the discretion of the staff members of the works-economics department, who should always bear in mind that, although working on behalf of the general manager, they are by no means superior to any member of the other departments, but have to create an atmosphere of confidence, so that these other departments work with them voluntarily and willingly.

The main work of organisation carried out in the works in question is discussed in detail in the publication referred to, the construction of the costing system, and the elaboration of the list of accounts are also explained. As already mentioned, this latter part of the publication is outside the scope of these articles. Many details of the other parts are familiar to readers of this series, therefore only examples have been reported which are necessary for maintaining continuity, or which are additional to former discussions.

Production Reports

The daily and monthly production reports are built up to the various demands of production control and costing : as far as it can possibly be arranged, the personal desires of the departmental manager in question have been taken into account, and uniformity is set aside, remembering that these reports should be designed to assist this manager and therefore are best adapted to his requirements. The reports are kept as short as possible, less in order to avoid unnecessary writing than to give an easier survey ; but care is taken that no important figures are omitted. These reports should give an analysis of production as well as of time. The time analysis should show the main, the auxiliary, and the lost times, and must give the reasons for the last ones. It is then possible to range the sources of stoppages in the order of their importance and to try improvements where they promise the greatest success. The analysis of production is not only built up by absolute figures of tons, pieces, length, etc., but special care is taken that fluctuations due to the various qualities of material and products, and of dimensions, are eliminated as far as possible by the use of equivalent figures, so that fluctuations by different stoppages, varying intensity of labour, etc., can more easily be recognised. The results are compared with carefully elaborated standards, based mostly on time studies, and it is considered that a satisfactory result is attained only when the production measured by a suitable equivalent figure and referred to the actual working time, fluctuates but little against the standard production. A daily report of the number of men in the service of the company, either working or absent by illness or leave, and of their total working time distributed over the various shifts, is closely connected with the production report. Care is taken that working time on Sundays and holidays and other overtime can be clearly distinguished, and that all these figures are summarised weekly and monthly for statistical purposes.

Organisation of the Internal Railway Traffic

As a special and temporary task is mentioned the organisation of the internal railway traffic, which was subordinared for some months to the manager of the works-economics department, as serious difficulties arose soon after the starting of production ; obviously, not sufficient precautions were taken to meet the demands not only of the proper production but also of the building of new shops and plants which continued during the initial period of production. The time table for arriving goods trains had to be established, the goods and materials distributed to the various destinations, and empty wagons returned quickly ; additional rail tracks were necessary, defective tracks had to be repaired and maintained, wagons suitable for the various shops had to be bought and put into regular use, and a maintenance shop for locomotives and wagons laid out, built and started.

The works were divided into several sections and a representative of the traffic department had to take care in each section to ensure smooth operation of the traffic according to the information of arriving and outgoing consignments, given directly from stores and receivers. This close connection between the traffic and production proved very successful; especially was this obvious from the decline of demurrage for public locomotives and wagons.

As the traffic costs were unusually high in these works because of the terrassed estate, the costs control was carried out more extensively than is usual : a budget was made showing the standard of costs per locomotive hour, separated for steam and non-combustion engines, and of the number of locomotive hours of each section. As soon as the organisation was running smoothly the management of the traffic department was handed over to a special manager engaged in the meantime for this position.

The Planning System

It may be possible when considering the planning system to distinguish between three purposes of this arrangement, all these directed to the same aim, the raising of economy—i.e., lowering the costs, increasing the output, and improving production methods.

The planning of costs had, of course, taken place before the decision to build the works, but it was repeated more in detail soon after starting production, and again a year later. The resulting cost statistics show throughout the actual costs in comparison with what they ought to be, not only for the whole works, but also for the individual departments and sections ; the comparison of the running month with the previous one is generally omitted as valueless because of the many contingencies which creep in ; the reports are prepared on printed forms more or less in the arrangement of tables, and as much as possible are illustrated by graphs, prepared and completed month by month by the works-economics department. These papers, containing few but all important and necessary data, form the basis for monthly meetings, directed by the general manager. Care has been taken that all important changes of the figures are explained on these papers, and these explarations are prepared by the works-economic department in conjunction with the responsible production department, in order to avoid any reason of ill-feeling. The monthly meetings take place between the 15th and 18th of the following month, the period of 2 to 2½ weeks giving time enough for careful preparation of the meeting and providing a suitable limitation of their duration, while presenting figures new enough to enable discussions to have a practical value.

With the two other purposes of planning, increasing the output and improving production methods, we approach the wide sphere, where especially work and time studies are the expedients for progress. Despite the fact that much about those problems has already been reported in these articles, I feel obliged to add at least one of the examples given in our source, because it may be of special interest to readers, in view of its object and the form in which it is explained. Fig. 28 shows the result of intensive studies of the cogging and finishing mill, where the original drive of a reversing two-high stand for ingots and of two-section stands by one motor and the non-existence of an intermediate mill made it very difficult to obtain the necessary output. The illustration should be self-explanatory, and further remarks are unnecessary.

Finally, attention is directed in this connection to the importance of time studies as a basis for the development of equivalent figures, which can be used advantageously (*a*) in daily, weekly and monthly production reports, (*b*) for determining fair piecework rates, and (*c*) for developing a comparatively simple calculation of class costs.

The Form of Statistics

In the foregoing remarks reference has already been made to statistics, but it may be useful to give a general survey of the principles, according to which the statistical work is done, and—what is more important and, unfortunately, often overlooked—used in practice. The statistics may be divided into those of costs and those of production. The former are, in the works in question, concerned with (*a*) total costs (*b*) charge costs, (*c*) manufacturing costs, and (*d*) general overhead charges. The most important of these groups for the workshops is the third one, and this group is therefore mostly subdivided. All data are given in the form of tables and graphs, and the trend of the figures is shown by recording the data for the months of the running year, one beside the other. As far as possible, the actual data are always compared with those assumed to be possible under present working conditions. The diagrams, showing the development of costs in graphical form, are not considered to be secret documents, but are posted up in the shops in question for continuous information and admonition of the departmental manager, his assistants, foremen and workmen.

The production statistics are closely connected with the cost statistics, but as they can be helpful for production only if they are built up according to the demands of production, they are often prepared in the offices of the shops, while the cost statistics are considered the duty of the costing department. This separation leads to duplication of work and even to discrepancies of the figures given from both sides. That is avoided in the works in question by making the internal statistics one of the duties of the works-economics department, which is familiar with this kind of work, since it delivers a great part of the basic figures from its investigations, time studies, etc. The production statistics are divided into those of output and of times, and the degree of efficiency is expressed in some coefficients, which show how far it is possible to obtain the practical ideal or standard. It has not always been easy to determine a fair standard, as those know who have tried to solve such a problem in practice, but here this question cannot be considered in detail.

The Wages and Bonus System

As the Iscor Works were the first iron and steel works in South Africa, it was first necessary to build up fair basic wages for all classes of workmen. In the first year after starting production wages were paid on hourly rates, but later a bonus system was introduced, according to some principles which were the same for all departments and sections throughout the works. Only two of these principles may be mentioned: the bonus has been built up on equivalent figures (equivalent tons, equivalent pieces, equivalent lengths, etc.), which alone guarantee that the dangerous "good" and "bad" piecework rates do not arise; the introduction of the bonus, in spite of the pressure from the productions departments, has always been postponed until some steadiness of production has been obtained, which made great fluctuations of the earnings of the men impossible. The careful and cautious introduction of the bonus system, without any major troubles by the workmen, can be considered as a great success of the works-economics department; it took many months before this important job was finished, and, it is obvious that this problem needs continuous attention

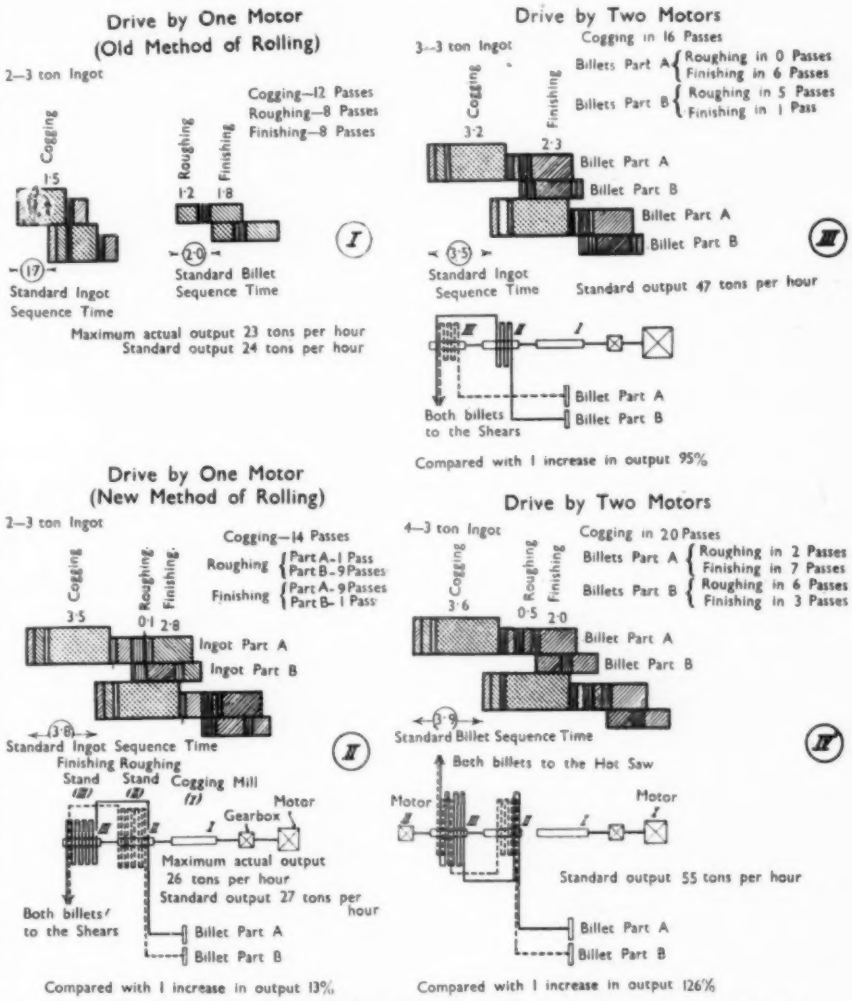


Fig. 28—Influence of weight of ingot, method of rolling and drive, on production of billets

since any change in the plants, in production methods, or any other working conditions, may lead to a change of the basic figures of the bonus system.

So much about the manner in which the duties of the works' economics department were determined and carried out in the works, which have here been selected as an example. It may be repeated that it is only an example. It would be difficult, if not impossible, to repeat the scheme to full extent in other works; personal questions especially, as well as former development and tradition, may produce difficulties when introducing such an organisation in existing works; difficulties which, of course, have been unknown in the case of a completely new undertaking. The reader, who may have drawn comparisons with the conditions, under which he has to work, will have certainly found out these differences and should be careful to avoid the mistake of severely criticising something because it happens to be different, without considering the reasons why differences should occur.

And therewith I come to the end of this series of articles on industrial administration and production control, knowing only too well that all I have been able to give are only sidelights on the problems involved, and that nothing can have been done by this publication for the improvement of actual practice where that impulse is lacking, which is mentioned again and again—the spirit of co-operation which only a real leader can create. Not in order to do justice to the present war-time, but because I have seldom, if ever, found how a true leader should be defined, so concisely and clearly, let me quote the French guide for infantry officers:

> "The officer must have a genuine regard for his men; he must have achieved something worth while; he must always act as an example; he must be able to sense what is practicable; and, above all, he must have character. He should be just, firm, and approachable, he must insist on implicit obedience, he must make clear to all what is meant by discipline and unity, and should establish them in his daily conduct; he must never shrink from assuming his responsibility."

The Influence of Alloying Elements on the Crystallisation of Copper

Part II.—Large Additions and the Part Played by the Constitution

MANY factors affect the crystal structure of an ingot or casting, the experiments described in this paper* by Dr. L. N. Northcott, however, have been devised in an attempt to avoid some of these, such as turbulence, and to standardise others, such as the temperature of the melt and the temperature, shape and material of the mould in order to determine the influence of chemical composition alone, this being one of the fundamental problems which remain to be solved. In a previous paper[1] it was shown from experiments with a large number of alloying elements that the effect exerted by *small* additions of the different elements was an inherent property of the element itself and was independent of the type of alloy formed by the element with copper. The influence upon crystallisation was also found to be largely independent of the freezing range when the relative effects of the different alloying additions were compared, but it was stated that the freezing range would be expected to play a part in the determination of crystal size in the freezing of the alloys of any one binary system

The investigation has now been extended to determine the effect of large additions of the principal alloying elements to copper, and in general, it has been found possible to correlate the tendency towards columnar crystallisation with the constitution of the binary alloy concerned. The results of this part of the investigation are described in the present paper. In all, eight series of copper alloys were examined, and these were chosen either on account of their commercial importance or as representing particular types of alloy constitution. The following is a list of the alloying elements used, with comments on each: (1) Zinc—has appreciable atomic solid solubility in copper and the alloys have a medium freezing range; (2) tin—has small solid solubility, wide freezing range, and the binary alloys are prone to suffer from oxide inclusions which may, however, be avoided by using a suitable deoxidation such as phosphorus; alloys with and without phosphorus have been examined in the present work; (3) aluminium—has medium solid solubility and very small to zero freezing range; (4) nickel—has complete solid solubility, small to medium freezing range; (5) manganese—has a very large solid solubility, small to zero freezing range; (6) phosphorus—is a gaseous deoxidiser, has little solid solubility, and large variation in freezing range; (7) magnesium—the copper end of the diagram is similar to that of the phosphorus-copper series, but magnesium-bearing alloys are very prone to contamination by entrapped solid magnesium oxide; (8) lead—has no solid solubility, and a wide variation in freezing range; two liquid phases are formed at certain compositions, and the high density of lead leads to segregation.

The proportion of each alloying element added was chosen in relation to the constitutional diagram. In the cases of zinc and lead, alloys representing the complete series were examined, but in most instances where compounds were formed, the range sudied extended only to the first compound. The results are presented in a series of curves in which the tendencies of the different alloys towards columnar crystallisation have been plotted against composition, the relevant constitutional diagrams also being reproduced.

An examination of the curves show that wholly columnar crystals occur in alloys solidifying at one temperature, but the presence of a freezing range tends to reduce the crystal length, although the reduction varies with the different alloy systems. An increase in crystal length is brought about by the peritectics at the copper and of the zinc-copper and tin-copper alloys and a decrease by the eutectic at the copper end of the magnesium-copper and phosphorus-copper alloys; the structures observed in these last two series of alloys were very similar. In general, the largest crystals were found in the aluminium-copper alloys. A few ternary and more complex alloys have also been examined. Explanations based upon the effects exerted by adsorption, freezing range, and the presence of a second phase have been put forward to account for the structures observed.

J. Inst. Metals, 1939, **65** (Advance copy).
[1] L. Northcott, *J. Inst. Metals*, 1938, **62**, 101.

"Matthey Cadmium Pigments."—A small two-colour booklet descriptive of these pigments which, with cadmium sulphide as a basis, can be obtained in any colour from pale yellow to orange, in the sulphide itself, or by the addition of selenium, of redder shades, giving a complete range from pale yellow to orange, and red to deep maroon. Copies may be obtained from Johnson, Matthey & Co., Ltd., London.

Manganese in Carbon Steels

By Bernard Thomas, F.Inst.P., M.Inst.M.

The manganese content in carbon steels, particularly those of hardening quality, is not only important, but critical. There are certain minimum limits below which quenching efficiency becomes impaired. The results of tests on steels of various manganese contents are discussed.

IN the category of straight carbon steels manganese remains an element of much interest to heat-treaters. In certain quarters it is still believed that, providing sufficient carbon is available, the results desired on quenching can be obtained regardless of fluctuations in manganese content. But this is not always the case, as has been dealt with previously in these pages in a general manner. The remarks which follow, however, are intended to describe in detail the influence which a difference of 14 points (0·14%) of manganese has on a nominal 0·50% carbon steel both in the hardened and unhardened state.

In Table I is given the analysis of the steel used in the tests. Both samples are basic open-hearth quality from the same source of supply.

TABLE I.
ANALYSIS OF STEEL SAMPLES USED.

Element.	Steel A.	Steel B.
Carbon	0·54%	0·53%
Manganese	0·67%	0·81%
Sulphur	0·036%	0·052%
Phosphorus	0·031%	0·038%
Silicon	0·141%	0·138%

It will be noted that while the nominal difference in manganese content is 14 points (0·14%), the normal effect of this is reduced to some extent by the higher sulphur content of the B sample, which will undoubtedly use up some of the manganese to form the sulphide of that element. Further, the A sample has the added advantage of one point higher carbon than B. It can be agreed, however, that the maximum difference between the two samples is certainly not more than 0·14% manganese either in percentage or potential effect.

Method of Testing Strips

To carry out the tests undertaken a device was constructed whereby machined strips could be manipulated for bend tests. The device consisted of a jig wherein the strips for test could be laid across bearers having 6-in. centres, and leaving the portion in between unsupported. Loading was applied by means of a standard Brinell hardness machine of the 3,000-kg. type, but using special weights calibrated to apply loads from 50 kg. upwards.

The movement of the strips under load actuated a pointer having an eccentric axis. The reverse end of this pointer moved along a scale graduated from 0 to 1·0 in. by 0·01 in. By estimating half the smaller divisions, it was possible to obtain readings with fair accuracy to 0·005 in. of deflection.

Strips for test were rolled to desired gauge, usually around $\frac{1}{8}$ in. thick, and subsequently machined down to 7 in. long by 1 in. wide in all instances. Care was taken always to ensure that dimensions were correct, and also the gauge the average of four readings minimum, owing to the influence which even slight differences could exert.

A specially-manufactured V-shaped tool with rounded apex was the means of making contact with the strips, a male portion carrying a thread being screwed into the place which carries normally the ball-holder in the Brinell machine.

The method of testing was to mount a strip in the jig, bring the nose of the bending tool just into contact with it, without actually applying any load, and then ensure the pointer was at zero on the scale. Load was then applied until the weight-arms lifted. In this respect it was not deemed sufficiently accurate to merely allow the arms to lift. Hair-line pointers were fitted to the body of the machine pointing along the weight-arms. The arms were caused to lift until marks scribed upon them came exactly in line with the indicating pointers. By this means it was possible to ensure that the arms reached exactly the same point in every test.

When the weight-arms lifted as described, indicating application of load, the test-strip would be bent to some given extent. The amount of this bend, or deflection, would be indicated on the scale by the pointer actuated by the strip. After noting the reading, the load was then removed, whereupon the strip would recover to some degree. The first reading indicates the temporary deflection or set, of the strip, while the second reading reveals the permanent set. Loadings were applied and removed continuously in suitable load gradations until such time as either the test-strip reached 1·0 in. of temporary set, or prior fracture.

Typical Figures Obtained

Table 2 will convey an idea of the type of readings obtainable from a pair of such tests. The figures relate to the thickest of three pairs examined in the hardened and tempered condition for the purpose of these notes.

To tabulate the whole of the tests undertaken would occupy much space and lessen probably the interest which otherwise might be taken in the results. The figures are shown, therefore, in graph form for easier assimilation. In Table II shown, however, it will clearly be seen the greater load necessary to reach a temporary set of 1·0 in. with the higher Mn, or B specimen, as compared with that of specimen A. That this trend persists will be seen subsequently from the graphs.

For the sake of simplicity, it is proposed in the text following to refer to Temporary Set as "T.S.," and to Permanent Set as "P.S.," and to the 0·67% manganese strips as "A strips," and to the 0·81% manganese strips as "B strips."

TABLE II.
TYPICAL BEND TEST FIGURES.

Load. Kilogs.	A Steel. 0·132 in. thickness. Set. Temporary. In.	Permanent. In.	B Steel. 0·132 in. thickness. Set. Temporary. In.	Permanent. In.
50	0·08	—	0·075	—
75	0·12	—	0·11	—
100	0·18	—	0·15	—
125	0·25	—	0·19	—
150	0·32	0·06	0·23	0·005
180	0·50	0·17	0·29	0·015
200	0·78	0·38	0·34	0·03
220	1·00	0·54	0·39	0·05
240	Indefinite	—	0·44	0·07
260	—	—	0·50	0·09
280	—	—	0·62	0·17
300	—	—	0·73	0·22
320	—	—	0·89	0·32
340	—	—	1·00	0·40
			Indefinite	

Graphs Described

Fig. 1 represents a pair of strips, 0·126 in. in thickness, tested in the "as-rolled" condition. Dealing first with the T.S., it will be noted that the "curve" for the A strips, proceeds to its conclusion in a line which is perfectly straight. The B strip, however, shows a considerable inflection before flattening out to terminate at the same point as in the case of strip A.

Reference should now be made to Fig 2, which covers tests on the Fig. 1 strips after the latter had been annealed. The A strip " curve " in the T.S. pair still remains perfectly straight, as might be expected, but the B strip has also followed suit, although at slightly higher readings. These slightly higher readings indicate the increased strength

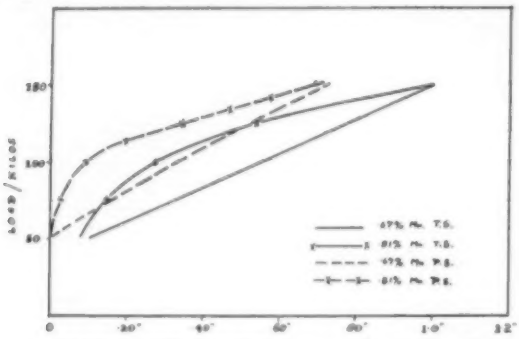


Fig. 1.—Strips 0.126 in. thick tested in the "as-rolled" condition.

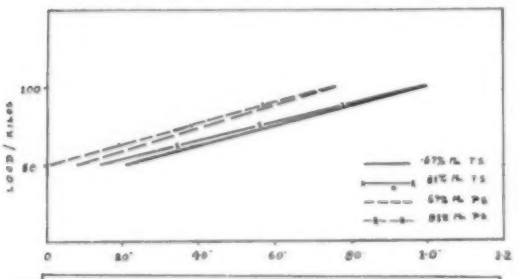


Fig. 2.—Similar strips tested after annealing.

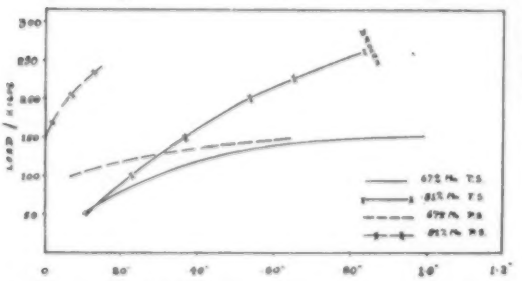


Fig. 3.—Strips 0.119 in. thick tested in the hardened and tempered condition.

promoted by the higher manganese content, but the chief point of interest is the particular lack of resistance to bending, as portrayed by absence of inflection, in comparison with B in Fig. 1. The inference to be drawn from this is that rolling produced a work effect in B strips which annealing destroyed subsequently. Such work effect was absent from A strips where the content of manganese was lower.

Similarly with the P.S. curves, while the figures for the annealed group yield a straight line for A and B steels, with the latter slightly the more resistant, the work effect of the as-rolled condition has caused an even sharper inflection in the case of B strip than was obtained on the T.S. readings.

Heat-treated Series

In choosing the strips for the hardening and tempering series of tests, three different thicknesses were selected. The object of this was to introduce the influence of mass on quenching. Relative thicknesses were as under :

Strips 0·119 in. thick, as covered by Fig. 3
" 0·125 in. " " " 4
" 0·132 in. " " " 5

In all cases the quenching and tempering treatment given consisted of quenching from 790° C. in fused salt at 180° C. and tempering at 265° C. for five minutes. Perhaps it should be explained that this particular temper was employed because it corresponded with that applied to a certain type of tool, in connection with which the tests as a whole were undertaken.

Dealing first with the thinnest strips of 0·119 in. thick as covered by Fig. 3, the T.S. curve of the A strip no longer runs out to its conclusion in a straight line, as it did prior to hardening. Primarily, the strip offers greater resistance to taking a set, and at a load of 100 kg. shows a T.S. of only 0·29 in. in comparison with 0·55 in. for the as-rolled state, and 1·0 in. in the annealed. The strip has a low yield point, however, and once a T.S. of 0·60 in. is

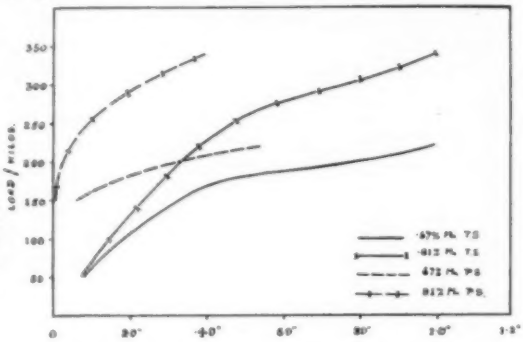


Fig. 4.—Strips 0.125 in. thick tested in the hardened and tempered condition.

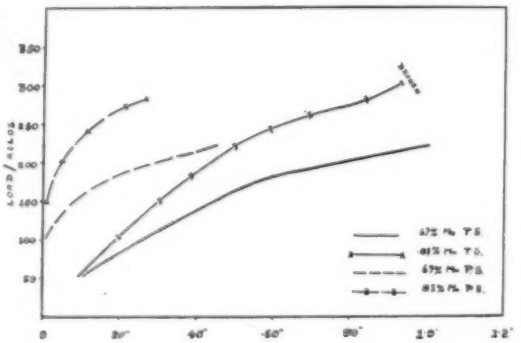


Fig. 5.—Strips 0.132 in. thick tested in the hardened and tempered condition.

reached the curve flattens out to 1 in. with only 13 kg. addition to the load.

It is in the hardened condition that the effect of the manganese becomes more noticeable. With the B strip in the T.S. results, the curve no longer flattens out, ultimately to end at 1·0 in. T.S. at the same load as the A strip. Instead, it soars upward continuously in marked contrast to the strip of lower manganese content. Readings cease at a loading of 260 kg. due to test-piece breaking. At this point a T.S. of 83 in. was recorded. The A strip was not sufficiently hard to break.

With the medium-thickness strips, as shown in Fig. 4, the T.S. curve of the A steel no longer flattens out after reaching a T.S. of 0·60 in., but continues to rise albeit less steeply. Comparing the two steels, at a loading of 220 kg., the A strip has reached the T.S. limit of 1·0 in., while strip B is only half that figure at 0·50 in. This gives z fair indication of the greater strength of the higher manganese steel. On continuing to load the B strip fracture occurred at a load of 300 kg. when a T.S. of 0·92 in. was recorded.

Reference to the P.S. curves will show that resilience is also present to a greater extent in B material than A. When the 220 kg. loading ended the test in the case of strip A, a P.S. of 0·45 in. was recorded. At the same loading the B strip showed only 0·08 in. Even at the loading prior to fracture the amount of P.S. amounted only to 0·26 in.

In the third, and last, group at 0·132 in. thickness, as covered by Fig. 5, there was obvious evidence that the influence of mass was making itself felt. Not only did the A strip acquire a greater P.S. after the final loading, but the B strip failed to fracture. In shop practice, of course, 0·125 in. is regarded as the reasonable limit of thickness for the particular quenchant employed.

With the T.S. figures for the A strip, the curve narrowly misses the flattening-out process. Actually, at a loading of 100 kg. the T.S. was a mere 0·18 in., as compared with 0·32 in. for the 0·125 in. thick contemporary, but this earlier promise was not maintained, and the test ended finally in each case at a loading of 220 kg. with a T.S. figure of 1·0 in.

Again, the B strip showed greater strength by first returning a T.S. of only 0·39 in. at the loading which ended strip A, and secondly by requiring ultimately a load of 340 kg. to reach the T.S. limit of 1·0 in. As in both instances previously, the T.S. curve rises more steeply and continuously than with strip A.

With the greater number of P.S. readings obtained with the B strip in the absence of fracture, the curve for same is more pronounced than ever, although a careful examination will reveal that for any given T.S. deflection the P.S. resulting therefrom is slightly higher in each case. This is a further indication of effect of mass on quenching.

When the A strip test was concluded a P.S. of 0·54 in. was returned after a loading of 220 kg. For a similar loading on B steel the P.S. was only 0·05 in., and subsequently reached a maximum of 0·40 in. in P.S. after a load of 340 kg. These figures once again indicate clearly the superiority of B strips over A in the matter of resilience.

Summary

In summarising the foregoing results, it would appear as under :

Annealed Condition. Difference slight, but noticeable in case of both sets recorded, in favour of B strips.

As Rolled. The results more pronounced in favour of B in earlier stages. Later when " work-hardness " is overcome, the difference becomes less marked.

Hardened and Tempered. (*a*) *Thin Strips* 0·119 *in.* The temper imparted by correct treatment has the effect of causing the B strip to continue in its superiority proportionately to the load applied, and not to flatten out at any given yield point.

(*b*) *Medium Strips* 0·125 *in.* Although A strips make an improved showing they remain inferior to B in the case of both T.S. and P.S. figures.

(*c*) *Thickest Strips* 0·132 *in.* Mass influence now beginning to make itself felt in quenching, but still the B strip returns the better results in both instances.

In general, the difference of 14 points (0·14%) of manganese, despite the disparity of carbon and sulphur referred to earlier, has been sufficient in the strips under test to cause two out of three of the B tests to fracture under load, while none of the A strips attained such hardness.

For the three heat-treated specimens, an average of 54·7% greater load was required to terminate the tests in case of B, as compared with A, and it is highly probable that this figure would have been higher still in the absence of fractured B strips at a T.S. of less than 1·0 in.

In connection with resilience, the minimum average loading required to produce a P.S. was 117 kg. in the case of A, and 150 kg. in the case of B strips, while the average of the final P.S. figures obtained at the conclusion of the tests was 0·55 in. for A strips in comparison with only 0·27 in. for those of B. From this latter it will be seen that the A steel had less than half the resilience of that of B.

In considering these tests as a whole, it should be borne in mind that the range of carbon employed for any given purpose has an important bearing on what the manganese figure should be, and also that under certain circumstances varying amounts of the latter element may exert similar influence to that outlined in these remarks.

Plastic Flow in Metals

A recent lecture by Prof. H. W. Swift to the Sheffield Metallurgical Association dealt with some problems in the plastic flow of metals. A brief report of this lecture is given, for which we are indebted to Mr. L. Rotherham, M.Sc.

IT is common procedure to study the behaviour of metals in the plastic range by means of the tensile test, but since the technically important part of this range usually occurs after necking has commenced, the true relationship between plastic strain and stress involves measurements of sectional area rather than elongation, and so demands a modified technique. The proved fact that elastic breakdown and plastic flow are substantially determined by the applied shear stress suggests that plastic stress-strain relationships could be obtained from either tensile compression or torsion tests, according to convenience ; and in this respect the torsion test has strong claims. But flow curves obtained from these different tests are only descriptively similar, and it therefore becomes necessary to study the stress-strain characteristics under various systems of simple and compound stress in order to obtain data of general quantitative value.

In most metals at ordinary temperatures the stress-strain relationship under simple, continuously increasing stress is approximately parabolic, but nearer to the melting point the parabolic rise is diminished and a flat characteristic is approached. The increased flow resistance following plastic strain is attributed to strain-hardening, but the Bauschinger effect, which gives rise to the familiar cyclic curves, shows that the material is in a mechanically unsymmetrical condition, and that hardness is not an infallible measure of resistance to plastic flow.

Since plastic flow takes time to develop, the rate of straining has an important effect on the stress-strain characteristics ; in the case of mild steel, the higher rates of straining produce a higher yield stress and greater yield range, a greater apparent rate of strain-hardening during the earlier stages of plastic flow, followed by a slower rate during the later stages.

The Bauschinger effect and the speed effect show that plastic strain is not a simple function of stress ; it is also a function of time and of the previous strain-history of the material.

Plastic strains are intrinsically distortional in character, volumetric strains remaining substantially elastic under all conditions. It is therefore natural that shear stress should be the predominant factor in plastic strain.

The geometry of strain as well as the geometry of stress can be expressed in a concise form in Mohr circle diagrams, whether the strains are small or large. Under elastic conditions, the stress and strain circle diagrams are geometrically similar, apart from the origin, the principal axes of stress and strain coincide, and the principle of superposition can be applied. Under plastic conditions there is some evidence that the principal axes coincide in isotropic material, but the principle of superposition is demonstrably invalid. The possibility that a simple correlation exists between stress and strain circle diagrams has been examined by Lode and by Taylor and Quinney, and it appears that materials subject to work-hardening do not provide similar diagrams for stress and plastic strain. A working knowledge of stress-strain relationships under compound stress must therefore await more comprehensive and elaborate experimental study.

Uncertainty regarding these relationships has led to the adoption for purposes of calculation of stress distribution of a hypothetical " perfectly plastic " material which is not subject to strain hardening at all. If a material of this kind were subjected to bending or torsion it can be shown that it would exhibit certain characteristics known to exist in practice ; the Bauschinger effect, cyclic curves of the familiar type, a residual stress distribution embodying previous strain history, and a relief of residual stress by

diminishing cycles of overstrain. It is suggested that a similar mechanism operates in local torsional and flexural fields under direct stress, so that no strain-hardening theory is required to explain cyclic curves or conditions arising from them.

Nature of Plastic Flow

In crystalline material the atoms are arranged in an orderly fashion, forming a lattice structure. Individual crystals are not isotropic, but a crystalline aggregate of grains with random orientations behaves isotropically.

In a crystal plastic flow normally arises from slip along certain favoured planes and in certain favoured directions. Slip is discontinuous in character; it occurs successively along an increasing number of more or less parallel planes, the material between the slip bands apparently remaining undeformed. During the process of slip the resistance of the crystal to further slip increases to an extent which cannot be explained by any changed orientation of the slip planes.

In a crystalline aggregate, individual grains are distorted in the above manner, but in directions varying from grain to grain and producing a statistically isotropic effect. The initial resistance of an aggregate and its rate of increase (strain-hardening) are both greater than in single crystals to an extent not explainable in terms of crystal grain orientation. There is experimental evidence that crystal boundaries play an important part in this stiffening. At higher homologous temperatures this effect is modified by the process of recrystallisation which restores the lattice structure, though frequently accompanied by crystal growth.

Theorists attribute strain-hardening in single crystals to internal strain causing distortion of the crystal lattice. Current conceptions of the nature of this disturbance fall into two groups—the mosaic theories, associated with the names of Griffith, Ludwik and Smekal; and the dislocation theories developed from different standpoints by Becker, Orowan, Polanyi and Taylor. According to the former group a secondary mosaic structure consisting of perfect crystalline units in a lamellar arrangement has weaker bonds than those associated with the primary atomic lattice, particularly along the faces of the lamellæ. Slip occurs between the lamellæ, causing a distortion which is variously supposed to take the form of continuous lamellar curvature, fragmentation into mosaic blocks along curved rows, or fragmentation into blocks which rotate individually and tend to lock the lamellæ against continued slip.

According to the dislocation theories, no primary significance is attached to the mosaic structure, but the perfect lattice is regarded as intrinsically weak. The atoms vibrate under their heat energy and under stress the laws of probability require a statistical displacement of atoms in a preferred direction, which macroscopically constitutes strain. This migration of atoms is explained either by lattice flaws, discontinuities, "stranger" atoms, or local centres of internal stress. In order to explain stoppage of flow and strain-hardening, it is supposed that dislocations are arrested by obstacles, such as a surface of misfit, a small flaw or the sphere of influence of a "stranger" atom; the local internal field of stress induced impedes atomic migration and so increases the resistance to further strain.

The greater resistance of a crystalline aggregate is ascribed to the action of the crystal boundaries in resisting distortion within the crystal. According to Beilby, an amorphous layer develops along the crystal boundaries, due to a partial breakdown of the crystal structure at surfaces of severe misfit, and as this layer becomes thicker its resistance to further deformation increases. Another and complementary rather than competitive theory pictures the grain boundaries as particularly severe barriers to lamellar slip in the mosaic structure, which intensify the buckling of the lamellæ and cause severe progressive rotation of the mosaic block units near the crystal boundaries, so that the lattice structure in these regions becomes distorted and eventually lost.

On the Nature of Certain Intermetallic Lattices

DATA on intermetallic phases are collected and examined in a paper by Dr. A. L. Norbury* from the point of view of the numbers of atoms plus electrons in the lattice, and the type of lattice. An empirical relationship is brought out, which indicates that the body-centred cube, close-packed hexagonal, and nickel arsenide-type basic lattices form "subsidiary" lattices of the same basic type by the process of atoms replacing electrons, or vice versa. This replacement of atoms by electrons does not alter the total number of atoms plus electrons in the lattice, but alters the electron : atom ratio and degrades the symmetry of of the atomic lattice, so that what may be termed a "subsidiary" lattice of the same type is formed.

For example, γ-brass is formed from 27 body-centred cube (three electron : two atom) units by two electrons replacing two atoms. This gives 83 : 52 as the electron : atom ratio, instead of 21 : 13, and $Cu_{21}Zn_{31}$, instead of Cu_5Zn_8. The "subsidiary," body-centred cube type lattices of the γ, γ_1, γ_2, ζ_3, η_2, and $CuAl_2$ phases in the copper-aluminium system are related to the basic lattice on the same principle. Similarly, the basic $7e : 4a$ close-packed hexagonal lattice forms subsidiary lattice at $13e : 9a$ and $15e : 7a$, and the basic $5e : 2a$ nickel arsenide-type lattice forms subsidiary lattices at $35e : 21a$, $37e : 19a$, $39e : 17a$, and $42e : 14a$.

In the above type of process, excess of one of the components of an intermetallic phase is accommodated in the basic lattice by ordered electron/atom replacement, with the formation of a "subsidiary" lattice. Accommodation can, however, also be made in a different manner by disordered atom/atom replacement, with the formation of an intermetallic solid solution having the same lattice. Both processes may be in simultaneous operation in an alloy of given composition.

It is suggested that the ordered process is due to energy exchange between the atomic electron shells and the free electrons, and that it tends to make them equivalent and interchangeable. Similarly, that the disordered process is due to energy exchange between the electron shells of solvent and solute atoms.

Nickel and Cobalt Oxides and Salts, Selenium and Tellurium

A VERY useful data book on nickel and cobalt oxides and their salts has recently been published. In both the electrolytic and carbonyl processes the oxide of nickel is produced in the later stages. This oxide, besides being itself a usable product, serves as a basis for the manufacture of the various salts of nickel. Cobalt refining necessitates various chemical treatments to produce an oxide of high purity and uniform quality. The final product of these processes, known as black oxide of cobalt, is the basis for production of metallic cobalt and its many compounds.

These oxides and their compounds, together with their known uses, are tabulated in this publication; also are given the applications of selenium and tellurium, both being found in the nickel-copper-ore bodies in the Sudbury district of Ontario. In addition to the tabulated uses, the book gives useful information regarding the application of these products in the various industries, or for special purposes. It is published by Henry Wiggin and Company, Ltd., Thames House, Millbank, London, S.W. 1, and copies are available, gratis, on request to this address.

Personal

MR. R. TURNER HOOD, formerly chief Scottish sales representative for Messrs. British Timken, Ltd., Cheston Road, Aston, Birmingham, 7, the manufacturers of tapered roller, ball and parallel roller bearings, has now been appointed Chief of the Mechanical Engineering Department of this Company.

* *J. Inst. Metals*, 1939, **65** (Advance copy).

The Hot Galvanising of Wire

By a Special Contributor

Brief reference is made to the mechanism of corrosion of iron and steel wire, and to the general principles of hot galvanising. Old methods are referred to and present-day technique is discussed in detail. Particular attention is given to the equipment included in the layout of a modern plant for dealing with heavy- and thin-coated wire.

UNFORTUNATELY, it must be accepted that corrosion is a necessary evil, and that whilst there is life so will there be corrosion, for the very agencies which are so essential to life itself will also initiate and favour corrosion. These corroding agencies cannot be stopped, and so methods of protection must be adopted. As galvanising is a process by which iron and steel wire is coated with a protective layer of zinc to prevent the base metal from corroding rapidly away, when subjected to ordinary atmospheric conditions, it is necessary to study the mechanism of corrosion and so form a true conception of the part played by zinc in its protective capacity.

The mechanism of corrosion is electro-chemical in nature, and as such requires an anode and a cathode in contact with an electrolyte. Ferrous metals are anodic and cathodic in nature as a result of their chemical and physical inhomogeneity. Carbon steels consist essentially of ferrite and pearlite (phosphides, silicides, etc.), which, when in contact with natural waters, set up a series of short-circuited electrolytic cells resulting in rapid corrosion of the ferrite constituent. Physical inhomogeneity results from differences in internal stress, a highly cold-worked or stressed section due to the increased "slip" of more favourably orientated crystals in the wire during reduction has a higher potential energy than a less cold-worked or less stressed section—the former is anodic to the latter and so corrodes more quickly than the latter. These two factors—viz., chemical and physical inhomogeneity in the presence of a suitable electrolyte—e.g., natural or rain waters—will result in the rapid corrosion of ferrous metals. The less the inhomogeneity in the metal the less will be the tendency to corrode, so that in well-annealed pure iron corrosion is absent. Rust is hydrated ferric oxide—$Fe_2O_3 + H_2O$ together with a little ferrous oxide—FeO—and carbonate of iron—$FeCO_3$. The result of the above electro-chemical reactions is briefly this: The electrolyte is essentially carbonic acid—H_2CO_3—which is a weak acid caused by the solution of atmospheric CO_2 in water. This acts on the iron to produce ferrous carbonate—$H_2CO_3 + Fe \longrightarrow FeCO_3 + H_2$—which is insoluble, but which is further acted upon by the H_2CO_3 to produce soluble ferrous bicarbonate $FeH_2(CO_3)_2$. This, in turn, is quickly oxidised by atmospheric O_2.

$$O_2 + 4FeH_2(CO_3)_2 \longrightarrow 2Fe_2O_3 + 4H_2O + 8CO_2$$

The liberated CO_2 acts on more available iron and results in more rust, which is colloidal in nature, but which in time crystallises, forming the stable iron hydroxide. The chemical and physical inhomogeneity in iron and steel wire cannot be obviated, nor can the presence of an electrolyte be avoided when the wire is exposed to atmospheric conditions. But if the electrolyte and atmospheric oxygen can be prevented from coming into contact with the iron base, rusting cannot take place. Many coatings are employed for this purpose and these can be divided into two main groups:—

1. Those affording mechanical protection—e.g., tin, lead, copper, paints, varnishes, oils, greases, cements, etc.; and
2. Those affording electro-chemical protection (i.e., sacrificial metals)—e.g., cadmium, zinc (which are anodic to iron, and so prevent the iron from corroding away.)

The protection afforded by the latter class is definitely superior, as it not only gives mechanical protection by interposing a mechanical protecting layer between the base metal and the corroding agencies, but also, by virtue of its higher electro-potential, is definitely anodic to iron and steel. Of the metals affording electro-chemical protection, zinc is the most widely used. In addition to the mechanical and electro-chemical protection afforded by this coating, a further protection is given by the fact that on exposure to air zinc forms a durable, resistant, insoluble double or basic carbonate of zinc, zinc oxide, and zinc hydroxide coating which adds materially to the protective nature of the zinc. It can thus be readily appreciated why a zinc coating on iron and steel wire is such an ideal method of protection against corrosion, and why galvanising plays such an important part in the wire industry.

Galvanising

Galvanising is a process by which the wire is coated with zinc, either by simple immersion in molten zinc or by electro-deposition. As the former method of coating—"hot galvanising"—is by far the most popular, and as the bulk of the wire galvanised in the world is by hot galvanising, this method will be the only one taken into consideration.

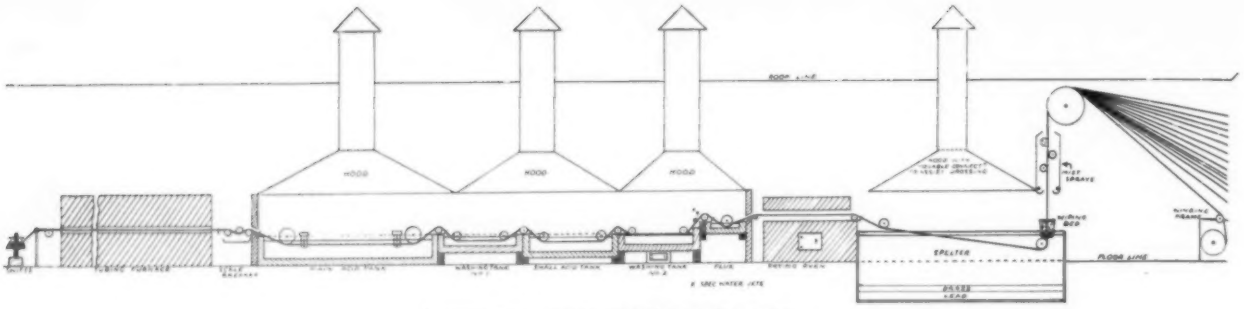
Hot galvanising can be divided into two sections, according to the weight of zinc coating and the finish required on the wire.

1. A thin-coated wire is one with a thin coat of zinc with a very smooth finish and a high polish, as in link, bedding, seating wire, and is wiped galvanised with pressure wipers to wipe all surplus zinc off the wire as it leaves the spelter bath.
2. A heavy-coated wire is one with a heavy coat of zinc, as in cable and fencing wire, and is lightly wiped through a prepared charcoal bed. Generally speaking, however, this class of wire has not such a smooth finish and polish as the wiped galvanised wire.

Both heavy- and thin-coated galvanised wire must conform to specification *re* tensile, torsions, bends, elongations, etc., and so both classes can be subdivided into "hard" and "soft" galvanising, according to individual requirements. The general principles employed in galvanising heavy and thin-coated wires are the same—it is only the details which differ.

General Principles

Briefly, hot galvanising of wire is the controlled immersion of cleaned and fluxed wire in molten zinc. The basic principles to be observed in hot galvanising are as follows: The wire, whether annealed or hard galvanised, heavy or thin coated, must be chemically cleaned and fluxed before immersion in pure zinc at the required temperature. Hot galvanising is generally done in strand form in one continuous operation, one coil being fastened to the preceding coil by the simple expedient "hook and eye" or by welding. The wire may or may not be annealed in the lead bath or tube furnace according to requirements, but in all cases the wire passes under rollers through hot or cold hydrochloric acid or hot sulphuric acid, then through a boiling water tank, again through another hydrochloric acid tank and a boiling water tank, through a fluxing tank



Layout of a modern galvanising plant.

of zinc chloride, ammonium chloride, or zinc ammonium chloride solution, over a hot plate, and finally into the spelter bath at approximately 450° C. The wire may leave the zinc bath vertically, on the slant or horizontally, according to conditions and requirements, and may be wiped through pressure or bobbin wipers to get a thin coat, or through a less severe wipe of charcoal and oil or charcoal damped with water to obtain a thicker coat of zinc. The wire is then cooled by direct immersion in water or passing over rollers on which run jets of water, and finally to the winding blocks.

Old Methods

Before viewing present-day technique in detail, it is both interesting and informative to review the older methods of galvanising.

Formerly, the galvanising department was a place where only stalwarts could exist—i.e., strong, hefty fellows with powerful lungs. The conditions under which they worked were very bad—bad lighting and ventilation, the atmosphere full of fumes from the coke-fired spelter pot, from the annealing pot, or coal-fired tubing furnace, acid fumes from the acid tank, and, above all, fumes from the fluxes. In those days, galvanising was an art jealously guarded by its followers. The old galvanisers were gifted with a lot of ca-canny, and in this as in many other old processes the rule-of-thumb methods reigned supreme. The tricks, gadgets, and rule-of-thumb methods accumulated by years of experience were handed down from father to son, and it is only recently that a scientific grip has been taken over the industry. Needless to say, the modern methods of galvanising are far superior to the older methods, and naturally so with the better facilities which are offered by all-round modern improvements of production and technique. Yet the older methods must not be ignored and despised as being worthless, for in some works these methods of production are still in existence; the old galvaniser can give the modern school some good ideas which are worthy of a place in modern galvanising technique. The advent of science has definitely proved the truth of many old institutions of thought and practice, and has really only provided a scientific explanation of the why and wherefore of these practices. Maybe the scientist will despise the saying, but, nevertheless, there are "tricks in every trade." Considering the facilities at hand and the conditions under which they worked, the old galvanisers did remarkably well. The old methods of galvanising consisted of running the wire off a swift, through a lead annealing pot or furnace to anneal the wire, then into acid to descale and clean the wire and at the same time flux it with iron salts, then into the spelter pot under sinkers, through a bobbin wipe or blanket of wet sand superimposed on dry charcoal at the exit end of the pot, and finally through a water tank on to the winding frame. The acid-house was the old galvaniser's sacred temple; this was the beginning and end of the whole process and was carefully guarded against intruders. The acid had not only to descale and clean the wire, but at the same time the iron salts present in the solution had to be employed for fluxing the wire and galvanising. Whereas modern practice may employ four or five tanks for preparing the wire for galvanising, the old practice had to do it in one tank. The galvaniser had to secure a careful balance between the efficient cleaning strength, temperature and density of the acid, and the efficient fluxing strength of the iron salts. A new tank of acid would not flux, a very old tank of acid would not clean. Hence the surreptitious syphonings of spent acid out of the acid tank, with careful additions of fresh acid, and agitation and activation of the acid with blocks of spelter and red-hot bars of iron. In addition, his wire was drawn from highly oxidised steel, which is definitely bad for galvanising; the surface finish of the drawn wire which had to be galvanised was not so good as present-day die-drawn wire; he had no temperature control recording instruments over his tubing furnace, nor was his furnace so well built as nowadays. The products of combustion scaled and contaminated his wire, making cleaning difficult. He had no thermometers, hydrometers, or titration methods of checking the temperature, density and strength of his acid tank; he did not have neutral fluxes to flux his wire and clean the surface of his bath. The quality of his spelter was not so good as the present-day electrolytic spelter. Yet, in spite of all these difficulties, a good galvaniser could secure fairly good results on both wiped and heavy galvanised wire.

The following are extracts from a letter received from a galvaniser 30 years ago, which well illustrates the galvanising technique of those days:—

The Metal Pot.—To test the heat of liquid spelter when gaiting up, thrust an iron bar, warmed, into the metal. If any metal adheres to the bar, the metal is too cold to start up with. If it runs quickly off the bar the metal is probably too hot. If the surface of the metal is of a brass colour it is excessively hot. To keep this metal at a uniform heat with 20–30 wires passing through is very difficult. The heat is carried forward from the back to the front, therefore the back part of the metal pot must be kept hot and the front part as cold as possible, as the back will feed the front with hot metal through the action of the wires passing forward. This refers to sand wiping, especially when the wire is tested for quantity and firmness of metal, as the metal must be in a thickish state at the front end of the pot. It may even be set round the sides and front, but a brisk fire must be kept going to keep it molten.

The Furnace should be got very hot to start up with, as it carries a false heat for a while after starting, and then rapidly goes cold.

The Acid Bath.—If gaited up new, mix with a few bottles of water. Dissolve a few sheets of zinc in acid at the back end, or a certain amount of the spelter if no zinc can be obtained. New acid will not act on metal (i.e., iron). To start with new acid so treated you must have as small a dip of the wires into the acid as possible—i.e., do not fill the bath too full. Look for the length of stroke made by the wire just entering the acid. This length determines the state of the acid in regard to its acting on the wire.

The Stretch and Twist Test.—This is determined by the length of red-hot wire between the furnace and the acid-house.

To be able to gauge the constantly changing heat of the spelter, it is necessary to observe these signs:—

If the wires carry sand after leaving the sand bed, the metal is too hot. This can be detected by passing finger and thumb along the wire.

If the sand turns black after being watered, the metal is too hot.

If the wires glitter after being watered through the sand, the metal is too hot.

If the wires are dull after the sand being watered, the metal is dangerously cold.

If the metal is too hot, drop plates of spelter in the pot about half-way, also put up the speed.

If too cold, slow down, get up fire till the foregoing signs are observed.

It is impossible to work for dips on a wire-wiping plant.

Never change acid on small job in small cisterns, but keep it quickened.

In a wire-wiping plant, the front end of the pot must be kept hot, as the wiper is a considerable way from the metal.

To Tell the State of Metal on Wire-wiping Plant.—If too hot, wipers are driven into the grid in front very tight, and begin to tremble and shake. The length of stroke of the metal behind the wiper shows the state of the metal. The longer the stroke on the wire, the colder it is.

To assure getting heat all round the wire-wiping pot, open damper on the floor. If red glare shows, the heat is getting round.

Much more could be said regarding the old galvanising technique, and more details given of the various layouts of the plants, but it is better to review the present-day methods, for, after all, the past has gone and the only purpose of reviewing it is to give us a greater appreciation of present-day methods and to indicate the changes which have meant so much in the improved quality of production.

Modern Methods

The basic difference between modern methods of galvanising and the old methods is that the wire is fluxed with neutral fluxes and not with acid fluxes. Modern practice insists on the wire being chemically cleaned, properly fluxed, and galvanised in the electrolytic spelter, free from dross and deleterious impurities. At first sight, this would not seem such a radical difference from older methods, but besides these basic differences there are a host of details all of which have a substantial bearing upon the quality of the galvanised wire.

Naturally, galvanising practice in different works varies as regards these details, and it is only natural that each works considers its methods to be the most efficient. Whether this is so or not must not be questioned, but it will be appreciated that in some cases quality of production is a feature which probably depends more on smart salesmanship and modern methods of advertisement rather than the outstanding merits of the galvanised wire. The best practice in galvanising is obviously one which is simple, cheap and effective, rather than one which involves many complications, needs constant supervision, and is expensive to run, and these points should be taken into consideration when formulating a good galvanising procedure. Another important feature which should not be disregarded is the " personal " or " human " element. The following present-day galvanising technique is based upon these generalisations.

Heavy Galvanised Wire

The Plant.—The size of plant naturally depends upon the maximum number and gauge of wires to be galvanised—thick wires obviously necessitating a plant of more robust construction than do thin wires, and a greater heat reserve in the spelter bath and annealing furnace.

The Swifts.—These should be situated at the ingoing end of the tubing furnace in two parallel lines, with guides between for the wires to lead up to the furnace. Allow sufficient space between the swifts for easy loading. On no account must they be movable or arranged haphazardly. They should be of the tilting collapsible type, so as not to necessitate the coils of wire being lifted on to the swifts, but simply pushed on—an obvious advantage when galvanising 3-cwt. pieces. Top arms should be included to do away with unsightly looking " bonnets," and upward curving bottom arms fitted to carry the coil and prevent loose waps from becoming entangled under the swifts and breaking. Have a brake on the swift for very springy wire, so that it keeps on the guide-arms to the tubes and does not foul other wires. Too much tension must not be employed with fine wire, as this causes the laps of the coil to pull up tight to the top of the swift and break. There is also a danger of the wire " pulling out " in the red-hot furnace, especially if it is very hot. Never load a cross-lapped coil on a swift unless it can receive individual attention whilst running off, as it is sure to break and to foul other wires.

The Tubing Furnace.—This should be sufficiently long and possess sufficient heat reserve to anneal all sizes of wire in strand form without going unduly slow. A good average length of furnace is 45 ft. The flues and combustion chambers should be so arranged that all the tubes can be heated evenly. When the wires run in two sets of tubes, one above the other, it often happens that the bottom set of tubes is hotter than the top set, due to it receiving the heat supply first. A single row of tubes would obviate this defect and result in each wire being as well annealed as its neighbour. The tubes must be gas-tight and kept free from scale, otherwise, if they leak, soot and products of combustion are deposited on the wires, especially at times of firing, and this fouls the acid, prevents good cleaning, and so results in poor galvanising. The furnace should be controlled by a two-point thermo electric pyrometer, the couples being situated in the first and last tubes, so that a furnace temperature of 800°-900° C. can be maintained irrespective of the size of the wire being galvanised. If the atmosphere of the furnace can be controlled or the ingoing or outgoing ends be water sealed, the wire will not be scaled and the subsequent cleaning in acid will be more efficient and more uniform.

Scale Breakers or Scaling Tank.—These can be dispensed with if the above non-scaling precautions be employed, but otherwise the scale is broken off by acute bending in two opposite directions over scale-breaking rollers or by quenching in water.

The Main Acid Tank.—This should be 12 ft. to 15 ft. long, about 3 ft. deep, and of sufficient width to accommodate all the wires. As there is no wear and tear of the lining, a rubber-lined brick or mild steel tank is the best, and will last indefinitely at a working temperature of 120°–150° F. The bottom of the tank should slope to an exit at one corner, fitted with a plug, so that the contents can be easily run off and the tank cleaned out. Pure synthetic hydrochloric acid is generally used in preference to the commercial acid, as the latter may contain a certain amount of arsenic. This plates out on the steel, forming black patches which will remain ungalvanised. The strength of the new hydrochloric acid bath should be approximately 10%, and should be heated up to a working temperature of 120°–150° F. by injected steam. Low-pressure exhaust steam could be utilised for this purpose. This temperature is maintained to a great extent by immersion of the hot annealed wire in the acid, and also by the following chemical reactions which are involved.

1. $Fe_2O_3 + 6HCl = 2FeCl_3 + 3H_2O$.
2. $Fe_3O_4 + 8HCl = 2FeCl_3 + FeCl_2 + 4H_2O$.
3. $Fe + 2HCl = FeCl_2 + H_2 \uparrow$.

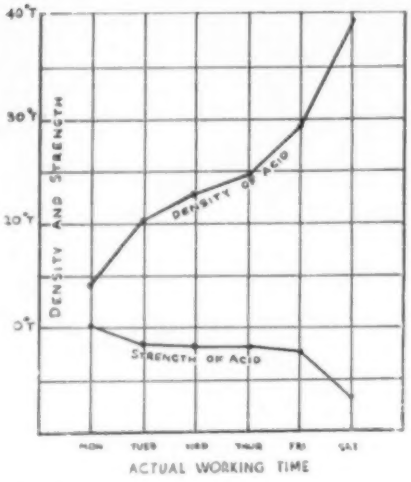
Reaction 3 effects greater chemical cleaning and mechanical descaling than reactions 1 and 2. The action of the acid is keener at the surface, but it is best to run the wires a few inches below the surface to allow a little working depth for draining off old acid down to the wire line when necessary and strengthening up with fresh acid.

As a result of the above reactions, the acid tank increases in density and decreases in effective strength. The temperature, strength and density of the acid must be carefully watched. The strength drops quickly after the first day's run—say, on the Monday—to about 6%, and this should be maintained for the rest of the working week, by controlled additions of fresh acid. The density increases in proportion to the amount of work being cleaned, reaching about 30°–40° T. by the end of the week. Work the acid tank hotter on the Friday night and Saturday morning rather than add fresh acid. Dump the acid on the Saturday and make up a fresh tank. The following chart should be entered up by the galvaniser and points plotted on the graph so that he can judge the working of the main acid tank. (See accompanying graph).

Use two grooved porcelain or earthenware rollers, one at the entrance end of the tank and the other at the exit end, with rubber-protected mild steel shafts or, better still, acid-resisting steel or Monel metal shafts. Monel metal paddles should be clamped on the shafts to agitate the acid. Two sets of guides of Monel metal or wood with stout glass

pegs should be fitted in the tank and dipping below the wire line, so that each wire can be separated from its neighbour.

From the main acid tank the wires pass into a tank 4 ft. 6 in. long, full of boiling water flowing in a direction opposite to that of the wire, then into a hot hydrochloric acid bath 4 ft. 6 in. long, at a temperature of approximately 150° F. and 8 per cent strength, and then into another tank of boiling water 4 ft. 6 in. long, at a slightly higher level, with the water again flowing in a direction opposite to that of the wire and feeding the first water tank with its overflow. The overflow from the second washing tank is utilised to maintain the temperature of the small acid tank, and the overflow from the first washing tank may be utilised to maintain the temperature of the main tank.



Day.	Date.	Gauge.	Density.	Carboys Strength.	Added.	Temp.
Mon.	—	10 G	14° T.	10%	—	140° F.
Tues.	—	10 G	20° T.	8½%	—	142° F.
Wed.	—	12 G	22½° T.	8%	2	129° F.
Thur.	—	14 G	24½° T.	8%	2	121° F.
Fri.	—	10 G	29° T.	7½%	1	140° F.
Sat.	—	6 G	39° T.	3%	—	152° F.
Sun.	—	—	—	—	—	—

It must be realised that the more effective the cleaning the heavier will be the coating of iron salts on the wires emerging from the acid, and the greater is the necessity of thoroughly washing off in boiling water. If the reaction products are not washed off, the flux will have to remove them, and this results in loss of flux, poor galvanising, and dross production. Immersion in boiling water also removes acid or hydrogen brittleness.

From the second washing tank the wires pass under a fine water jet into warm " killed spirits " or zinc chloride. This flux is prepared by neutralising 50% synthetic hydrochloric acid with electrolytic spelter. Ignore the dark-grey deposit which is mostly lead. Put several handfuls of " flaked " zinc pellets in to kill the last traces of acid. The flux improves on ageing, and should stand several weeks before using. The warm wires from the washing tank help to maintain the temperature of the flux tank.

The wires then pass through a drying furnace situated at the ingoing end of the spelter bath. This makes the flux " tacky," and prevents excessive spitting when dipping into the spelter, and also drives off the last traces of occluded hydrogen. Do not completely dry the wires, as the presence of traces of moisture results in better fluxing.

One precaution must be taken in the treatment of wire from the annealing furnace to the spelter pot—the wire must be exposed as little as possible to atmospheric oxidation from one tank to another.

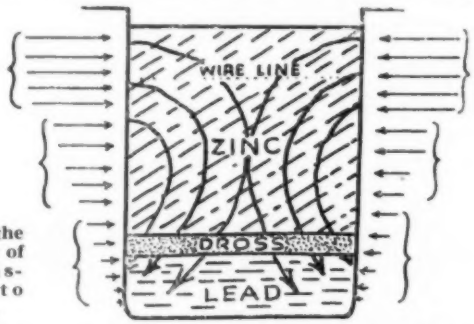
The wires enter the spelter through a clean zinc surface, free from zinc ash accumulations. This is best achieved by raking the zinc oxide from time to time away from the wires. Molten fluxes sometimes used for this purpose are quite good, but there is always the danger of the flux, when spent, contaminating the wires and carrying through. In time the wiping bed becomes affected, wiping is less satisfactory, and blue stains appear on the wire.

The Spelter Pot.—The best electrolytic spelter of a composition approximating to the following analysis must be used: Zn 99·95%, Pb 0·03%, Fe 0·02%, with Cu, Cd, and Sn each below 0·001%. If possible, mix several brands of electrolytic spelter together to ensure uniformity of analysis. Test occasionally for deleterious impurities—e.g., Fe, Cd, Sb. Cd and Sb particularly must be guarded against, as these result in bad coiling and bending of the galvanised coat; both have a more pronounced hardening and embrittling effect on Zn than Fe has. Cd also makes the protective layer of $FeZn_7$ on the bath sides porous and granular, so that it falls away, leaving fresh surfaces to be attacked by the molten zinc.

The size of pot for a 30-wire frame should be approximately 12 ft. long × 4 ft. deep × 3 ft. wide, containing about 6 in. lead, which remains at the bottom on account of its specific gravity, the remaining 3 ft. 4 in. being spelter. Never fill the pot above the rivets along the reinforced rim of the bath, as the likelihood of failure is greater here than anywhere else. One or two rollers may be immersed in the zinc, but only one immersed roller is essential, the other should be racked backwards and forwards along the surface of the spelter, to control the length of immersion of the wire—thicker wires with heavier zinc coatings will necessitate a longer immersion than a fine wire. The time of immersion is controlled by the speed, but it is advantageous to be able to control the length of immersion as well.

Bearings and rollers immersed in the zinc should be of a metal least attacked by molten zinc. The rate of solution of iron in molten zinc increases directly in proportion to the amount of impurities and dissolved oxide in the iron, carbon, phosphorus, silicon, etc., definitely lower the resistance of iron to zinc attack. Hence, ingot iron with a very low solubility loss in molten zinc is generally used. A 6% nickel steel is supposed to be unattacked by molten zinc, whilst manganese steel is particularly durable under these exacting conditions.

The method of firing the pot is particularly important, and it is generally accepted that bottom and bottom-side firing is bad in that it has a tendency to " boil " the dross, preventing it from settling out and so contaminating the wire. The pot should be top-side fired at the point where radiation losses are greatest, by carefully controlled methods of heating, such as surface combustion or radiated heat. Both these methods do away with flame impingement and its resultant evils. In the radiated heat method of heating, a series of controlled gas burners impinge on refractory material inserted between the burners and the sides of the bath, which radiates heat to the bath. In the surface-combustion method of heating, specially controlled flames produce a blanket of intense heat which floats round the bath. Refractory baffle plates are inserted to control the amount of heat which enters the bath sides from the top to the bottom. In the accompanying diagram the intensity of heat transmission to the bath is indicated by the size of the side arrows. The downward thrust of the dross is indicated by the arrows in the pot. It can be readily seen what effect must result from bottom heating. The direction of the arrows inside the pot would be reversed, the heat would pass through the dross, and this would be forced up, contaminating the working portion of the bath. On the other hand, side-firing as indicated results in a downward thrust of the dross, leaving the working portion as pure as possible.



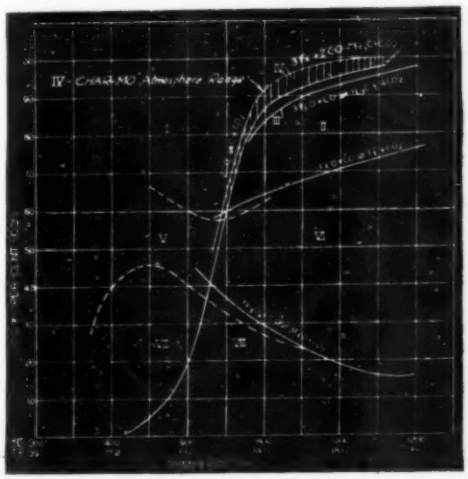
Indicating the intensity of heat transmission to the bath.

(To be continued)

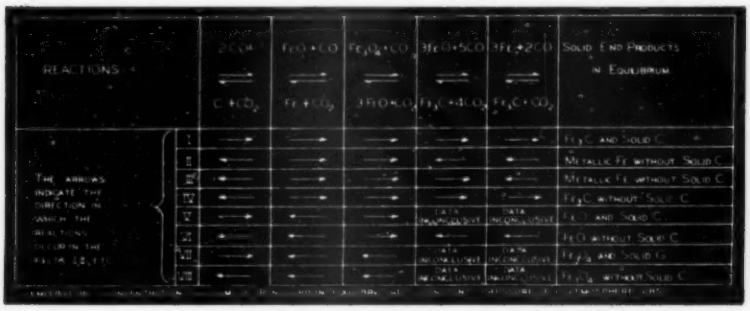
Recent Developments in Materials, Tools and Equipment

New Furnace for Heat-Treating High-Speed Steel

A CONTROLLED atmosphere furnace is constructed by British Furnaces, Ltd., which successfully and easily heat-treats molybdenum tool steel, as well as other high-speed and carbon tool steels, without decarburisation and without the use of borax or other protective coatings. The main feature in the operation of this furnace is the application of the development of "Char-mo" atmosphere, a highly refined gas, the composition and flow of which can be controlled so as to be in equilibrium with all types of steels. This atmosphere is a mixture of balanced carbon oxides, largely diluted with inert nitrogen.



Iron-carbon-oxygen equilibrium diagrams.


REACTIONS
THE ARROWS INDICATE THE DIRECTION IN WHICH THE REACTION OCCURS IN THE FOUR LETTERED AREAS
SOLID END PRODUCTS IN EQUILIBRIUM
Fe3C AND SOLID C
METALLIC Fe WITHOUT SOLID C
METALLIC Fe WITHOUT SOLID C
Fe3C WITHOUT SOLID C
Fe3O4 AND SOLID C
FeO WITHOUT SOLID C
Fe2O3 AND SOLID C
Fe2O3 WITHOUT SOLID C

Authorities:—

$$2\,CO \rightleftharpoons C + CO_2$$ — BOUDOUARD

$$FeO + CO \rightleftharpoons Fe + CO_2$$
$$Fe_3O_4 + CO \rightleftharpoons 3\,FeO + CO_2$$
$$3\,FeO + 5\,CO \rightleftharpoons Fe_3C + 4\,CO_2$$
$$3\,Fe + 2\,CO \rightleftharpoons Fe_3C + CO_2$$
— MATSUBARA

The dotted lines are those of Baur and Glaessner.

As will be noted, the accompanying equilibrium curves show the carbon oxide ratio $\frac{(CO)^2}{CO_2}$ in equilibrium with carbon according to the reaction $2\,CO^2 \rightleftharpoons C + CO_2$ to be greater at all temperatures than the ratio in equilibrium with Fe_3C according to the reaction $3\,Fe + 2\,CO \rightleftharpoons Fe_3C + CO_2$ at the same temperatures.

Area marked IV between these two curves defines the range of carbon oxide ratios which are non-decarburising to iron saturated with Fe_3C in solid solution at the particular heat-treating temperature, and free from formation of solid C or soot. Carbon oxide ratios in this range, under conditions of low velocity of the atmosphere surrounding the work, come to equilibrium with the work without decarburisation or carburisation. As the rate of flow is increased, carburisation is effected in proportion to the amount of CO carried to the surface of the work.

It is apparent from the chart that carbon oxide ratios in area IV are always greater for a given temperature than those in area II above the equilibrium curve for $FeO + CO \rightleftharpoons Fe + CO_2$. Thus any carbon oxide ratio which is non-decarburising is automatically non-oxidising for all hardening and annealing temperatures. This statement does not apply to steels bearing a considerable amount of chromium, since chromium is oxidised by pure CO. However, such chromium steels are so slightly oxidised that it is possible to produce colours on the work during heat-treating, similar to colours associated with tempering temperatures.

In selecting a non-oxidising and non-decarburising atmosphere for all types of steel, molybdenum steel can be regarded as the supreme test. It is the one steel that does not form a protective oxide film as a self-protection against decarburisation. Thus, Char-mo atmosphere not only protects molybdenum steels against decarburisation, but is an admirable atmosphere for all types of steels—both high-speed and carbon—such as are used in the manufacture of tools, dies and parts subject to excessive wear, which require to be heat-treated. This atmosphere is non-carburising to all steels, but its composition can be controlled to be neutral or slightly carburising as desired. The operation is dependent on the rate of flow of the gas over the work, the flow being closely controlled according to the requirements of the work. It is non-oxidising to all steels except those containing a considerable amount of chromium, which, during heat-treatment, becomes coated with a film of chromium oxide.

The furnace is designed as a self-contained unit producing and utilising Char-mo atmosphere. It incorporates a reaction retort in which the gas is produced, and a hopper for charging the retort with charcoal. Two types of furnaces are available—a horizontal muffle type and a vertical muffle type for temperature ranges of 760°–1,010° C., and 1,096°–1,350° C. A variety of muffle sizes are standard in both types.

The Wellman-Galusha Gas Producer

THE problem of making gas from low-grade fuels has long been the subject of research and experiment with a view to developing the most suitable machinery for this purpose. Resulting from intensive experimental work of this character is a machine which has been specially designed for the efficient gasification of grades of fuel such as $\frac{3}{16}$ in. to $\frac{3}{4}$ in. anthracite beans and very small coke breeze—fuels previously considered suitable only for use under boilers, and then only workable on special stokers. This machine is the Wellman-Galusha gas producer, which, from low-grade fuels, produces an ideal gas for all industrial heating purposes at a cost considerably below figures previously regarded as the minimum.

The machine is a self-contained unit comprising four main parts: an overhead fuel bin from which fuel is constantly supplied to the machine; a water-jacketed producer shell in which gasification takes place; a high-efficient revolving grate which is mechanically operated;

and a conical ash-bin in which ash is collected as it is automatically discharged by the grate. In operation this producer is practically automatic, very simple to control, and capable of running continuously for long periods, delivering clean gas of uniform quality under widely fluctuating load conditions and requiring the minimum of attention.

Several installations of this gas-producing plant are in operation, and in many cases installations have been extended by additional machines. Their application has resulted in considerable economies in the ceramic, metallurgical and chemical industries, and it is claimed that, in many instances, the quality of products has been improved by the installation of these machines.

The Wellman-Galusha gas producer is designed and constructed by the Wellman-Smith-Owen Engineering Corporation, Ltd., Victoria Station House, Victoria Street, London, S.W. 1, who have just published a brochure describing this machine. Of considerable interest is a typical gas cost sheet which sets out the formula to be used to ascertain the cost per therm of gas produced from anthracite and from coke.

Canada's Mineral Production in 1939

The mineral production in Canada during the year 1939 is estimated to have reached a total value of $470,179,000, an all-time high record, representing an increase of 6% over the previous year, and of 3% over 1937, when the previous highest total was reached. New output records are reported for antimony, gold, copper, zinc, nickel and cadmium. Several new gold mines reached the production stage, and the gold productive field was widened. Iron ore was produced on a commercial scale for the first time in 16 years at Michipicoten, and this was perhaps the most significant development of the year in the mining industry.

A considerable amount of prospecting and development work occurred in connection with the search for those metals and ores which have not as yet been produced to any great extent in Canada, but which are important for war purposes in the manufacture of various alloys. These metals include molybdenum, manganese, mercury and tungsten. In the output of refined copper, nickel, lead and zinc, Canada is now in a better position to assist in the successful prosecution of the war than at the outbreak of war in 1914. Since that time, large refineries have been established in the Dominion for the production of the above metals.

The following table shows the estimated quantity and value of the principal metals produced in Canada last year, the figures for 1938 being given for comparison:

Metals.	1938.		1939.	
	Quantity.	Value.	Quantity.	Value.
		Dollars.		Dollars.
Gold	4,725,117 oz.	97,676,834 (par)	5,046,000 oz.	104,305,000 (par)
Silver	22,219,195 ,,	9,680,239	22,745,000 ,,	9,238,000
Nickel	240,572,938 lb.	53,914,494	227,090,000 lb.	51,099,000
Copper	571,249,664 ,,	56,554,034	606,705,000 ,,	60,721,000
Lead	418,927,600 ,,	14,008,941	391,499,000 ,,	12,375,000
Zinc	381,506,588 ,,	11,723,698	394,956,000 ,,	12,066,000
Platinum metals	292,219 oz.	8,874,156	292,000 oz.	9,368,000

Metal Prices Increased

In the three months September to November the non-ferrous metals group showed a small increase of 4½%, but the substantial price increases authorised by the control for copper, lead and spelter and the decontrol of tin prices caused the index for December to rise by about 8%. Iron and steel were mostly unchanged until November, when the aggregate for the group showed an increase of about 8½%. In general, pig-iron prices advanced by about 7½ to 9%; steel billets and tin and sheet bars, 13½%; and finished steel, 6½ to 11%. Tinplates were on the average some 25 to 30% dearer in October than in September, and the averages for November showed further rises of about 18 to 23%.

The Influence of the Rate of Cooling on the Transformation and the Properties of Vanadium Steels

TWO series of vanadium steels of 0·5% and 1·0% V, and of 0·3% to 1·7% C, have been investigated by thermal and micrographic methods, with continuous increase of the rate of cooling, by Franz Wever and Adolf Rose. The influence on the transformations and properties of the vanadium steels has been illustrated by under-cooling diagrams.

With the vanadium steels the pearlite transformation is lowered at the first stage to about 600° C. without changing its character for the range of cooling rates till about 20°/sec. The segregation of vanadium carbide is suppressed, the segregation of ferrite and cementite of the hypo- and hyper-eutectoid steels is unchanged. The structures show transitions from a mixture of pearlite and ferrite to sorbite with the hypo-eutectoid steels; transitional structures of spherical cementite to sorbite with the eutectoid steels, and sorbite, beside needles of cementite, with the hyper-eutectoid steels.

At the second, or intermediate, phase a new independent transformation could be observed from a cooling rate of about 15°/sec. The pre-eutectoid segregation of ferrite is suppressed. The temperature of decay of austenite decreases from about 525° with low content of carbon to about 450° with a carbon content of 1·5%; it is independent of the rate of cooling. The transformation of the second stage is always connected with recalsecence. The segregation of cementite of the hyper-eutectoid steels can still be clearly discerned and is displaced to lower temperatures. This second degree is marked by a structure of needles similar to martensite, clearly distinguished from the pearlite of the first degree. With the hyper-eutectoid steels, structures of mixture with cementite needles could be observed. The hardness decreases at the hypo-eutectoid and hyper-eutectoid steels, but increases at the hyper-eutectoid steels with increasing cooling rate.

The third phase, that of martensite, begins at higher cooling rates, and covers finally the total course of transformation. The temperature of the martensitic transformation is the same as with carbon steels, and independent of the cooling rate. The structures of this phase do not differ very much from those of unalloyed steels; the martensite is mostly very fine. The hardness increases, at eutectoid steels, with increasing cooling rate up to a maximum of 900° to 950°. At very high rates a decrease takes place in consequence of the increasing influence of untransformed austenite.

These observations can be interpreted as follows: At the first stage of under-cooling the segregation of vanadium carbide is displaced very quickly to lower temperatures. It introduces the process of transformation at small cooling rates, and moves with increasing cooling rate slowly to the end of the transformation. The increase of hardness in the pearlite stage, as well as the tempering hardness, can be explained by segregation of vanadium carbide.

The processes in the second stage of under-cooling cannot yet be explained accurately. From the decrease of hardness, and especially from the missing tempering hardness of steels which have been transformed in this second phase, the conclusion has been drawn that a process of transformation takes place. The processes of the third, the martensitic, phase can be explained in the same manner as has been done for the martensite of carbon steels in former publications.

The behaviour of vanadium steels at high cooling rates places them between carbon steels and high-alloy chrome-nickel steels, which have also been the subject of earlier investigations.

Franz Wever and Adolf Rose. Mitteilungen des Kaiser-Wilhelm-Institut für Eisenforschung in Düsseldorf. Vol. XX. No. 16.

Solutions to Some Metallurgical Problems

By L. Sanderson

Many problems that confront the metallurgist have a special urgency, since solutions are required for immediate application in practice. Considerable experience, as well as technical ability, is necessary to achieve success, and in this article the author indicates a few of the many problems presented for urgent solution and the manner in which they were solved.

NEW problems are continually being investigated by the metallurgist. Below are given a few of these, with their solutions. Some valves employed in the production of a synthetic chemical were required to work at very low temperatures—e.g., approximately —150° F. These had to handle a pressure of about 600 lb. per sq. in. A high impact value was desired, with a minimum value of 15 ft.-lb. of absorbed energy on the Charpy machine. After considerable experiment, a form of ternary steel alloy casting was developed possessing the following analysis: Carbon, 0·08%; manganese, 0·29%; silicon, 0·12%; nickel, 4·06%; molybdenum, 0·5%; vanadium, 0·16%. To obtain the desired properties, the castings had to be given a normalising treatment of drastic type, followed by quenching in oil and tempering at a relatively high temperature.

In another instance, a steel of extremely high elastic limit was required for a certain machine part rotating at exceptionally high speed. No vibration or shocks were met with in use, the stresses being wholly radial and tangential, due to centrifugal force. For this the metallurgist developed a nickel-molybdenum steel containing 0·45–0·55% carbon, 0·5–0·8% manganese, 1·65–2·0% nickel, and 0·2–0·3% molybdenum. The proper heat-treatment for this steel is oil quenching from 785°–815° C., followed by tempering at 535° C. This steel thus treated possesses excellent elastic properties. An even higher elastic limit can be obtained from the same material if the tempering temperature is less than 535° C. This, however, will partly reduce the toughness.

Recently, the metallurgist has been asked to find a material for the support blades of centreless grinders. For these parts, the best metal is a nickel-chromium alloy cast iron containing 3·0–3·5% carbon, 0·6–1·1% silicon, 4·25–4·5% nickel, and 1·5–1·75% chromium. Such an iron should not be heat-treated, but a stress relief annealing at a temperature of 235°–315° C. should be given, after which a Brinell hardness of approximately 500–650 will be obtained.

In manufacturing ball mills, baffle bars are sometimes fitted about the internal circumference of the casing to stop the grinding media from slipping on the casing's surface. The metallurgist was asked to suggest a steel that, while withstanding the abrasive action of the balls, would be relatively easy to machine, tough, and unlikely to fracture when the bars were being bolted fast. For these baffle bars a steel was recommended containing 0·55–0·65% carbon, 0·6–0·9% manganese, 1·0–1·5% nickel, and 0·45–0·75% chromium. This steel is tough, abrasion resistant, and gives a Brinell hardness of 400. It is more machinable than a carbon steel of higher carbon content, and should be quenched in oil from 800°–815° C., and tempered at about 510° C. to give the specified Brinell numeral. If greater hardness and abrasion resistance are desired at the expense of toughness and machinability, it is essential to reduce the tempering temperature. If the bars are to be machined in advance of heat-treatment, the tempering temperature must be lowered to 370°–400° C. This will give a Brinell hardness of approximately 500, and the steel will still be tough enough not to fracture when being installed or during work. The temperatures mentioned must be maintained for at least one hour per inch of thickness of the bars.

Grappling hooks are another problem for the metallurgist. The problem is to find a steel of adequate ductility that does not require heat-treatment in the larger sizes—i.e., that can be used in the as-forged state. An alloy steel is the metallurgist's recommendation, and preferably one tough and fatigue-resisting. That recommended contains nickel and chromium and gives a Brinell hardness of approximately 225.

A widely different problem, but one of some importance in certain fields, is a steel suitable for the compressor rings of ice compressors. The rings are usually from 1 in. to 12 in. outside diameter, 1 in. wide, and $\frac{1}{8}$ in. thick. The steel from which they are to be made is in plate form, must be capable of withstanding low temperatures and the resulting tendency to embrittlement, tough, and offering high strength in all circumstances. The most satisfactory material developed for this purpose is a steel containing 3·5% nickel and from 0·3–0·4% carbon. This has adequate strength, and is obtainable in the form of structural plate. It retains its toughness remarkably well at sub-zero temperatures. As an alternative, a 2% nickel steel with approximately 0·2% carbon is possible, as it is tough at low temperatures.

Toolholders are often drop-forged, but have a bad habit of warping after heat-treatment. The metallurgist has been called upon to supply a steel for them which will have minimum distortion, and yet possess satisfactory strength. His advice is the employment of an alloy steel containing 0·35–0·45% carbon, 0·5–0·8% manganese, 1·65–2·0% nickel, and 0·2–0·3% molybdenum. This needs the following heat-treatment; quench in oil from 800°–830° C. This heat should be maintained for about an hour before the quenching takes place. Tempering should be at 375° C. for about 1 hour, after which the steel should be cooled in air. This will give a Brinell hardness of 415. The steel should be annealed after the forging has been carried out and in advance of machining. This is done by heating to 870°–900° C., maintaining for 1 hour at this temperature, and allowing to cool in the furnace.

A steel with a low coefficient of expansion, but at the same time possessing a Brinell hardness of 300 constitutes a most difficult requirement. Since low expansion is associated with an austenitic grain structure, to obtain a 300 Brinell by heat-treatment is impossible. The metallurgist has not, perhaps, completely solved this problem, but he has gone some way towards it. His method is to alloy the low-expansion metal known as Invar with beryllium. This enables the metal to be given a certain degree of hardness, although the coefficient of expansion is increased to some extent. A beryllium addition in the neighbourhood of 1% enables the Brinell hardness of the material to be increased from 180 to 365.

Cast-iron baffles in oil heaters quickly burn out in some localities. This is due to two factors. In the first place, the castings are probably functioning at temperatures from 40° to 80° C. hotter than they should. Secondly, there is probably some corrosion due to sulphur gas. For sintering grate bars, the metallurgist has put forward a nickel-chromium cast iron containing 2·9–3·3% carbon, 2·2–2·6%

silicon, 0·6–0·8% manganese, 0·7–0·8% nickel, and 0·8–1·0% chromium.

Track rollers, when made from case-hardening carbon steel, tend to flake at the case and crack, probably because the core is not strong enough to withstand the severe loads. To overcome this difficulty, a steel containing 4·5% nickel and 1·5% chromium is advised by the metallurgist. It gives a greater degree of resistance to wear, together with fewer cracks and flakes. It needs a case-hardening treatment on the following lines: Carburise at 900°–925° C. quench straight from the pot into oil. Reheat to 785°–815° C. and quench in oil. As this metal has a very fine grain, case and core can both be refined with a single quench.

The wheels of trucks handling industrial materials have to be strong and to wear well. Their diameters range from 4 in. to 6 in., and they weigh from 6 lb. to 2·5 lb. For these the metallurgist specifies a nickel-molybdenum alloy cast iron of the undermentioned analysis: 2·8–3·2% carbon, 0·6–0·8% manganese, 1·25–1·75% nickel, and 0·3–0·5% molybdenum. The silicon content varies with the wheel section, being from 1·8–2·4% for wheels of less than 0·5 in. section, and 1·5–2·0% for wheels from 0·5 in. to 2 in. section.

Corrosion of Zinc

An investigation on zinc corrosion is discussed. Experiments were carried out in the laboratory, and comprised atmospheric exposures under controlled humidity conditions and exposures by water immersion; particular attention was paid to the role of carbon dioxide in the corrosion process. The corrosion product of zinc, under certain conditions, has been identified.

MANY of the commercial applications of zinc and of alloys high in zinc depend on their resistance to corrosion. Careful studies of zinc corrosion by E. A. Anderson and M. L. Fuller,* leading to more efficient utilisation of this important metal, are therefore of interest to the zinc industry and to all users of the metal and its alloys. The experiments which were carried out in the laboratory resulted in the identification of the corrosion product of zinc under certain conditions of exposure and in observations on the mechanism of its formation. Atmospheric exposures under controlled humidity conditions and exposures by water immersion were investigated, and particular attention was paid to the role of carbon dioxide in the corrosion process.

The principal method employed in the investigation was that of electron diffraction. By this method surface corrosion films, too thin to be visible to the eye or to X-ray diffraction examination, may be detected and identified. X-ray diffraction and chemical analyses were also used, when corrosion products were of sufficient bulk to utilise such methods.

In using the electron diffraction method, it was observed that zinc surfaces were usually coated with a film yielding a characteristic diffraction pattern, the film being of sufficient thickness to prevent the photographing of the diffraction pattern of the underlying metallic zinc. It was found that the diffraction pattern of the film was similar to that obtained by previous investigators from the skin which formed on the surface of molten zinc and to a limited extent on solid zinc. This film was regarded as zinc oxide, but this supposition was not established by chemical analyses. When a sample of precipitated basic zinc carbonate was prepared and photographed in the electron camera, there was a close similarity between the diffraction photograms of the precipitated carbonate and of the zinc oxide. It was therefore considered by the investigators that the skin removed from the surface of molten zinc was really ordinary hexagonal zinc oxide when in contact with the molten zinc, and that after removal it became converted to basic zinc carbonate by the action of atmospheric carbon dioxide and moisture.

To show that the corrosion product was basic zinc carbonate, and to compare it with basic zinc carbonate formed by precipitation from zinc sulphate and sodium carbonate, electron diffraction photograms were made of zinc surfaces corroded by the immersion at room temperature for two and three days respectively, of clean rolled zinc in distilled water saturated with air, and by the exposure of clean zinc at room temperature in air of 33% relative humidity. The similarity of the photograms established the similar nature of the corrosion products.

The essential role of carbon dioxide in the ordinary corrosion of zinc was further demonstrated by experiments conducted in the absence of carbon dioxide under which conditions the corrosion film was entirely different, being zinc oxide and not basic zinc carbonate.

To determine the composition of the corrosion product, chemical analyses were made of three independent samples prepared by immersing large sheets of zinc in distilled water for three weeks. The average analysis was as follows:—

	%
Total Zn as ZnO	71·8
Total CO_2	9·4
H_2O	14·0
	95·2

The ratio of Zn O to CO_2 calculated quite closely to 4 Zn O, CO_2, and on the basis that the water content was nearly 4 molecules the empirical formula of the product was found to be 4 Zn O, CO_2, 4 H_2O. An alternative manner of writing the formula would be Zn CO_3, 3 Zn $(OH)_2$, H_2O, which would indicate that the corrosion product might be regarded as a basic zinc carbonate with the manner of combination of water uncertain. This assumption would account for slight observed differences in the electron patterns in the number and intensities of diffraction rings in several specimens, due to difference in the degree or state of hydration or carbonation.

Some of the corrosion product obtained by immersing zinc in distilled water saturated with air for several days was removed from the zinc backing and examined by electron and X-ray diffraction and analysed for CO_2. By the electron method, the basic zinc carbonate structure was indicated, by X-ray diffraction the material appeared to be mostly hexagonal Zn O with some basic carbonate, while chemical analyses showed CO_2 content to be 5·6% This experiment indicated that the initial corrosion product was zinc oxide, which subsequently became converted to basic zinc carbonate. In this experiment the particular product was in the form of zinc oxide coated with basic zinc carbonate, since electron examination showed only the coating of the particles of basic zinc carbonate, and X-ray examination revealed the total structure as zinc oxide plus basic zinc carbonate. A repetition of this experiment revealed basic zinc carbonate only by both electron and X-ray examination, showing that complete carbonation had been effected. The fact that water and air in the absence of carbon dioxide produced a zinc oxide corrosion product appears to confirm the theory that zinc oxide is the initial corrosion product which in the presence of CO_2 and H_2O becomes converted to basic zinc carbonate.

That the corrosion product was basic zinc carbonate also appeared to be confirmed by its behaviour on heating.

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By electron diffraction it was found unchanged after heating at 100° C., but became partially converted to ZnO at 200° C. and completely converted to ZnO at 300° C. Corresponding X-ray examination indicated the complete conversion to take place as low as 200° C. Similarly, precipitated basic zinc carbonate loses most of its CO_2 by heating at 300° C.

The changes undergone by a clean zinc surface under various exposure conditions and for various lengths of exposure, were also studied. Exposures were made in air in closed desiccators at 33 and 75% relative humidity at room temperature, using saturated solutions of magnesium chloride and sodium chloride respectively for the two humidities ; and also in water at room temperature. In each series of experiments, the specimens were exposed cumulatively, being removed from exposure at selected intervals for inspection and replaced. In the water experiments, immersion for 5 seconds produced no apparent change, but after 30 seconds' exposure the zinc was coated with a film of basic zinc carbonate, which showed no change after immersion for 40 days. Zinc immersed in water for three days and then placed in a desiccator containing sodium hydroxide as the essential ingredient of the desiccating agent, and examined at various intervals up to 28 days, showed the corrosion product to remain unchanged as basic zinc carbonate. After 84 days, however, this carbonate appeared to be partially decomposed since hexagonal zinc oxide as well as basic zinc carbonate was detected.

Zinc exposed to air at 33% relative humidity appeared unchanged after one day, but after two, three, four and nine days' exposure electron examination indicated basic zinc carbonate as well as zinc at the surface of the metal. After 14, 21, 28, 36, 49, 79 and 106 days, the zinc was sufficiently coated with basic carbonate to prevent detection of metallic zinc. The behaviour of zinc exposed to air at 75% relative humidity differed in two respects from zinc exposed at 33%. In the former, the basic zinc carbonate film formed and apparently completely covered the zinc in from one to six days, and the basic carbonate also showed a preferred orientation. As this preferred orientation varied with different specimens of zinc, it appeared that the physical structure of the carbonate film varied with the humidity. The corrosion of zinc placed in a desiccator with sodium hydroxide without previous immersion in water was found to be greatly retarded. Some basic carbonate was detected after 14, 28, 42 and 55 days, but the film was not sufficiently complete to mask the underlying zinc until 98 days of exposure.

The corrosion experiments dealt with were based entirely on laboratory tests, but it seems likely that similar phenomena takes place during outdoor exposure, complicated, of course, by ever-changing weather conditions and the presence of corrosive gases other than those met with in the laboratory. Extension of the investigation to zinc corroded out of doors is now being made, and preliminary results indicate that the product of outdoor weathering may be basic zinc carbonate, basic zinc sulphate, or both. Under certain conditions chlorides are detected in outdoor corrosion products.

The Nickel Industry in 1939

WORLD consumption of nickel, in all forms, during the first ten months of 1939 totalled 206,000,000 lb., according to a review by Mr. Robert C. Stanley, Chairman and President of the International Nickel Company of Canada, recently published. This figure compares with 160,000,000 lb. and 201,000,000 lb. consumed during similar periods of 1938 and 1937, respectively. This record consumption may be attributed to the great improvement in the heavy industries in the United States and Canada, and to the general speeding-up of industry in Europe and other parts of the world, in order to augment the production of necessary war supplies.

An important extension was observed for the strong, low-alloy, corrosion-resisting steels. Marketed as proprietary products by leading alloy steel producers, a majority of these steels now are of the nickel-copper alloy type. As rolled, they combine moderate cost with improved strength properties and highly satisfactory response to shop fabrication, including cold forming and welding, and they have improved resistance to corrosion in the atmosphere and certain other environments. Volume increased markedly, and these steels have become useful in railroad rolling stock, in the mining industry, in oil-field tubular goods, in truck tanks, trailer frames, etc.

Nickel continued to occupy a primary place in the field of heat-treated constructional steels. A low cost, low-alloy nickel-chromium steel, introduced commercially a few years ago, is in use for front-end parts of a prominent passenger automobile, and during the year found applications in other fields. Nickel-chromium-molybdenum steels of certain types have become recognised as providing machinability at high hardness. Their selection is indicated when accuracy and fine finish necessitate machining after heat-treatment.

Stainless steel manufacturers have enlarged their facilities and improved their methods of rolling this useful alloy steel. The improvement in the product and the extension of the knowledge of fabrication techniques have increased its use. Nickel ranging from 8 to 26% is an important constituent in the major portion of the production of these steels. The well-known type, 18—8, containing normally 18% chromium and 8% nickel, accounted for more than half the total produced. Next to the constructional steels, stainless steels represent the largest market for raw nickel.

Metallurgically, the most important features have been the expanding use of additional alloying elements, such as molybdenum and columbium, and the introduction of new types, such as the "leaded stainless," to the already successful free-machining stainless steels. During the year attention has been directed to the improvement of stainless steel by the addition of small quantities of silver. Because of the difficulty of dissolving silver in the steel bath, it is usually added in the form of an alloy of 95% nickel and 5% silver.

Non-ferrous mills are running neck and neck with steel mills in promoting recently developed products that eliminate weight through higher strength, resist corrosion, or cut down fabricating costs. It is by no means a competitive race, as the two groups perform in different fields. Non-ferrous metallurgists have been as active as steel metallurgists in developing new and improved products which have been as actively promoted.

Supplementing regular products, such as aluminium, brass, copper, nickel-silver, monel and nickel, the non-ferrous mills have developed, and are promoting, a number of non-ferrous alloys that can be hardened thermally. The most recent development is "Z" nickel—a 98% nickel alloy that will develop 160–240,000 p.s.i. tensile strength with corresponding hardness. Rustproof fish hooks for salt-water use have recently been made of this alloy, which is being employed for many other wire and strip products such as springs, diaphragms, camera parts, automobile antennæ and high-strength rustproof wire rope. Other recent developments in hardenable non-ferrous alloys include "K" monel and a casting alloy "S" monel, used for valve seats and similar purposes, because it retains a hardness of 320 to 370 Brinell at 1,100° F. and has excellent resistance to galling.

Reviews of Current Literature

Tables for Converting Rectangular to Polar Co-ordinates

THE main object of the tables given in this book is to facilitate the conversion of rectangular co-ordinates (x, γ) to polar co-ordinates (γ, θ) by means of the relations—

$$\gamma = \sqrt{x^2 + y^2} \qquad \theta = tan \frac{-1\, y}{x}$$

The arrangement adopted is the result of several years of experiment, and is believed to afford the maximum possible efficiency. The tables are intended for use with a calculating machine or slide rule ; it will be found that only one set-up of the machine or rule is usually necessary, and that no intermediate working need be recorded. In the case of the slide rule, however, two settings may be necessary when the maximum accuracy is desired. In order that the method will be well understood, the author gives a number of examples in considerable detail.

One extensive use that has already been made of these tables in manuscript form is the transformation of harmonic constants a and b, obtained by harmonic analysis, to amplitude c and phase angle ϵ, in accordance with the relation—

$$c \sin (nt + \epsilon) = a \sin nt + b \cos nt$$

The use of these tables for the evaluation of inpedance and phase lag or lead from resistance and reactance will immediately suggest itself to electrical engineers. The evaluation of the magnitude and direction of a vector from rectangular components and the conversion of complex numbers from the form $x + i\,y$ to the form $re^{i\theta}$ are further applications.

Included in the tables is a table for reducing angles to the first quadrant, which provides all necessary information for dealing directly with angles up to 27 revolutions in degrees or 36 revolutions in radians ; for larger angles the reduction is readily made in two stages. The method of use, in this case also, is explained.

By J. C. P. MILLER, Ph.D. Published by Scientific Computing Service, Ltd., 24, Bedford Square, London, W.C. 1. Price 2s. net.

The Machining of Copper and its Alloys

THIS book discusses in a comprehensive manner the machining properties of copper alloys, and summarises modern machining practice as applied to these materials. Much of the data presented has been culled from technical literature, but a large proportion has been obtained through the courtesy of machine-tool makers and firms engaged in the production of copper alloys. The information from these sources has been supplemented by means of machining tests, carried out by the Copper Development Association on a comprehensive range of copper-base materials.

The range of copper-base alloys now available to the engineer is so wide that, even in a book dealing exclusively with these materials, it is not possible to make reference to the machining properties of each and every alloy ; hence some form of grouping or classification is essential. In this book copper alloys are discussed in three groups, the materials in each group having similar machining characteristics, but while this is a very convenient arrangement, it must be realised that no two copper alloys possess identical machining properties, and, in consequence, reference is frequently made to individual alloys. The three groups comprise the homogeneous materials, the lead-free duplex or complex alloys, and the leaded alloys : these are defined and explained in the initial chapter.

Copper alloys with an ultimate tensile strength of 40–50 tons per sq. in. are now commonplace, while for special duty strengths up to 80 tons per sq. in. can be developed by means of heat-treatment. Obviously, such high-duty materials should not be machined with the same tools nor at the same cutting speeds as those permissible for the older brasses and bronzes, and the information given in two chapters on general machining practice will be especially helpful, since they deal with modern practice. They discuss tool design, rigidity, cutting-tool materials, speeds and feeds, and cutting fluids. In a further chapter attention is directed to miscellaneous machining operation, including turning, shaping and planing, facing, parting and forming, automatics, knurling and thread rolling, and also to the machining of porous bearings. The drilling, boring, reaming, screwing, and tapping of copper alloys are also discussed, and a chapter deals with milling, sawing, broaching, and grinding.

The engineer can rarely afford entirely to overlook the question of machinability when selecting the particular copper alloys for his products, even though it may appear to be of secondary importance, and the chapter discussing the selection of copper alloys for machining purposes will be especially useful to the engineer and designer. This book, which is adequately indexed, carries a number of useful tables, and is well illustrated. It not only serves as a practical handbook, but as a guide to the choice of materials for machined products.

Copies can be obtained free of charge on application to the Copper Development Association, Thames House, Millbank, London, S.W. 1.

The Physical Examination of Metals

VOL. 1.—OPTIC METHODS.

THE demands of modern industry have led in recent years to a very striking advance in our knowledge of metals. This knowledge has come very largely from the application of scientific methods to the investigation of metals ; and since the properties of metals that determine their usefulness are chiefly the physical properties, it is generally appreciated that the examination of metals by physical methods is now of great importance. To-day, certain physical methods of examining metals have become such an ordinary part of the metallurgist's technique that they have come to be regarded as metallurgical rather than physical methods. An example is the investigation of phase changes by cooling and heating curves. But while such methods have been incorporated as metallurgical methods, a number of physicists have been investigating various properties of metals by methods that are practically unknown to those metallurgists without special training in physics. Such methods are often viewed with suspicion or are ignored by metallurgists.

In this book the author explains the physical theory underlying these methods, describes the more important applications that have been made, and, where possible, describes the technique so that the reader can apply it. The book is to be published in two volumes, and this, the first volume, deals with optical methods. It is pointed out that although all the effects of geometrical optics, wave optics, and polarisation can be accounted for in terms of the wave theory of light, there are certain other effects for which this theory offers no explanation. The quantum theory is invoked in order to supply an explanation of these effects. Such cases which are those in which the emission and absorption of light by matter are concerned, are beyond the scope of this book, and will not be considered in it, although certain examples, such as the photo-electric effect, will be discussed in the second volume.

The main subject matter in this volume is presented in five chapters, which deal with geometrical optics, wave optics, polarisation, and a concluding chapter on sources of light. It is difficult to do justice to this volume in a short review of this nature, but it can be regarded as a useful contribution to the literature on the physical examination of metals, and can be recommended to those who desire to be more fully acquainted with the physical theory underlying these methods of examination and their more important applications.

By BRUCE CHAMBERS, B.Sc., Ph.D., F.Inst.P. Published by Messrs. Edward Arnold and Co., 41-3, Maddox Street, London, W. 1. Price 14s. net.

Metals in the Service of Mankind

By A. Pinkerton

From the time of flint tools to the present day, Mr. Pinkerton, in his recent Presidential Address to the Birmingham Metallurgical Society, briefly surveyed the discovery of metals, tracing progress by reference to outstanding developments in non-ferrous fields, a short abstract of which is given in this article.

FOR many thousands of years the tools and implements necessary for life were supplied by flint and stone. In the course of searching for suitable material for making such tools, which was mostly found in the river beds, a shining, yellow sort of stone must often have been noticed, but not until someone found that this stone could be beaten into any shape desired was it realised that it could be put to any useful purpose. In some such way was gold discovered. Native gold is ductile, and was easily beaten into shape by the stone tools then available, but too soft to be itself used in that capacity. Its use was, therefore, confined to ornamental purposes, and ample evidence of this is found in ancient remains. Gold leaf was made in Egypt in the first dynasty, about 3,400 B.C., and was 0·001 mm. thick.

It is generally supposed that in regions where gold and copper both occurred in the native state the former metal would be the first to attract the attention of primitive man on account of its lustre. Copper, as is well known, when exposed to the atmosphere would tarnish and become covered with a black or green coating according to circumstances. Even so, it would be discovered that they too could be shaped by hammering, and that such treatment hardened the material; repeated heating and hammering would show that it could be given a sharp edge or point. This discovery would indicate its superiority to stone or flint for the making of tools, since it had the further advantage that, when it became blunted, the edge could be renewed. Pure copper would not make ideal tools, and although implements made from the native metal have been found in Chaldean and Egyptian remains the earliest use of copper, like gold, was mainly for personal decoration.

When or how the discovery was made that metals could be smelted from their ores can only be conjectured. Many suggestions have been put forward as to how this process originated. It is probable, however, that the discovery was made at the camp fire when some stones of malachite had been used for building the hearth, which, under suitable conditions, would be reduced to metal.

The introduction of bronze marked an important step forward in the history of metals. The date of its first use is uncertain, but it was known in Egypt in the third dynasty, about 2,900 B.C., but its use in that country is not credited till about the eighteenth dynasty, from 1,580 to 1,250 B.C. The Sumerians are said to have used bronze earlier than 3,000 B.C., but subsequently to have reverted to the use of copper, possibly owing to a shortage of tin. The first bronze was probably made accidentally, by the inadvertent mixing of copper and tin ores. This seems to be proved by the fact that the early so-called bronzes either contained very little tin or widely varying amounts of that metal. It has been said that primitive man could not have reduced tin ores by the methods then available, but Professor Gowland, by simulating ancient practice, has shown that an alloy containing as much as 22% of tin can readily be made by such methods.

The earliest brass was made by heating a mixture of zinc ore and metallic copper in a crucible, the heat being sufficient to reduce the ore. It is said that an alloy of 23% zinc and 77% copper was known in Palestine about 1,000 B.C. However, this is rather uncertain, as the names used for copper, bronze, and brass were used rather indiscriminately in ancient records. For this reason, it is often uncertain which metal is indicated. Brass was certainly known in Roman times, in which it was used for coinage as well as for personal ornaments and decorative work.

During the Greek and Roman periods the production of metals was greatly increased. The latter people in particular extended their use in many directions; they made considerable use of copper and bronze, the latter being used even for surgical instruments and artificial limbs. A delicately fashioned artificial leg dating from about A.D. 300 made from bronze sheet which was originally fixed to a wooden core by means of bronze nails, is preserved in the museum of the Royal College of Surgeons. Bronze and brass was used extensively for coinage, and the former alloy was used for engineering purposes.

In the development of the copper industries, it is learned from Agricola that considerable progress had been made on the Continent, but Britain had fallen far behind. It was in the reign of Henry VIII that a beginning was made to revive this industry and to establish the brass industry, but it was not until Queen Elizabeth's reign that much progress was achieved. The help of foreign labour was sought, as well as capital for this purpose. A beginning was made in 1561, mines being opened in the Keswick district and smelting works started. Before brass could be made, a supply of calamine had to be obtained. Deposits of this mineral were ultimately found in Somerset, and so all the materials for making brass were available in this country. Works were erected at Tintern Abbey for the drawing of wire as well as for the making of battery goods in 1665.

In spite of extensive privileges granted and the prohibition of imports of copper and brass, the new industries developed slowly. The wire drawers, wire card makers, girdlers and buckle and clasp makers all complained that they were being supplied with inferior metal at high prices. Decline set in during the Stuart period, and it was not until after the restoration that any signs of revival were present. Mining in Cornwall was revived, and deposits of copper ore were found and worked in Anglesey. Smelting was started at Neath in South Wales, and at St. Helens in Lancashire. Brass works were erected at Bristol, Cheadle, Macclesfield, and in several places in Yorkshire.

Advances were made during the 18th century both in the production of copper and brass and in their application to manufactures. First must be noted the pumping engines of Newcomen and Watt. The mines in Cornwall were usually deep, and water proved a considerable obstacle to working them. By the aid of Newcomen's engine and later by the steam engine of Watt, it was possible to pump the water from the mines and so enable them to be worked to a greater depth. The next noteworthy invention was the introduction of the rolling mill. Prior to the beginning of the 18th century the forming of brass and copper sheets and plates was carried out by the process of battery. By this method the cast slabs were flattened out to the required thickness by hammers, power being supplied by water wheels. Pans, kettles and other hollow-ware, as well as strip for making wire, were produced in the same way. In 1697 a rolling mill was introduced for making sheets at works

in Surrey, and this was followed shortly afterwards by the installation of similar plant at Maidenhead and Mitcham copper works. These were driven by water-power.

Simple rolling mills were, no doubt, in use for rolling lead before they were applied to the less ductile metals, and until the end of the 16th century wire had been drawn, in England at any rate, by man power. This was a very slow and laboricus business, and it was superseded by water power at the works set up at Tintern Abbey, it being part of the monopoly granted to the Mineral and Battery Company. It was not until the end of the 17th century that it came into general use.

The casting of metals is a very old process, and bells had been cast in England for some centuries. Cannon were also cast in this country during the 16th and 17th centuries at foundries in London and Surrey. At the beginning of the 18th century this method was adopted. for the manufacture of small brass articles. Stamping was also first introduced about this time, John Pickering, a toy-maker of London, was the first to see its possibilities, and applied it to the making of ornaments which could be produced by stamping much more easily than by the laboricus method of engraving. The new process was taken up by others, Richard Ford and John Smith introducing it to Birmingham for the making of such articles as saucepans, warming pans, basins and ladles.

The chief advance in the making of brass during this period was the use of metallic zinc in place of calamine. The date when this metal was first discovered is uncertain It is claimed by some to have been found in Egyptian remains, and it had undoubtedly been found in the crevices of furnaces where the vapour had condensed during melting, although it is doubtful if it was recognised. Erasmus Ebener had shown that copper and zinc could be used for making brass in 1580, but it was not until 1781 that James Emerson obtained a patent in this country for the producing of brass by this method, and it did not come into general use until the 19th century.

Another process which came into use about this time was that of plating. The credit for this invention is usually given to Thomas Bolsover, of Sheffield, who in 1783 showed that silver could be plated on to copper for making light articles. The process was not a commercial success in his litetime, but another Sheffield man, Joseph Hancock, took it up later and applied it to the manufacture of candlesticks, teapots and the like.

It was during the 18th century that the metal trades were established in Birmingham, but, as early as the 16th century, the town was famous for its metal workers. In 1538, Leland describes it as a place full of smiths. As a result of this long experience, the inhabitants were able quickly to adapt themselves to the working of brass and copper. The manufacture of these metals continued to increase in Birmingham, but, owing to a move among the smelters to control the price of copper, the Birmingham manufacturers became concerned about their supplies, and endeavoured to obtain an interest in the smelting industry and establish the manufacture of brass in the town. In 1780 a company was formed, known as the Birmingham Metal Company, for making brass, and ten years later the Birmingham Mining and Copper Company was established. By this means, Birmingham freed herself from the monopoly which had been set up, and by establishing the manufacture of brass in the town, paved the way to becoming the centre of the brass trade, not only in this country, but for a time at least in the world.

This century, too, saw the development of another new source of power—that of electricity,—which made possible many new methods of manufacture. One of the first uses to which it was put seems to have been that of electrodeposition, and by the middle of the century electrolysis was firmly established. Metallurgists were not slow to recognise the high purity of the copper so produced, and it is of interest to note that Dick, in a paper published in 1856, describes the use of such copper in a study of melting and casting. The earliest patents taken out in this country for the electro refining of copper were those of J. B. Elkington in 1865 and 1869. By 1890 six plants for electrolytic refining were in operation, the largest having an output of 60 tons per week. In 1937 about 80% of the copper used throughout the world was refined by this method.

These are only a few of the discoveries and inventions made during the 19th century that had a profound effect on the development of metallurgy. Many new metals were being introduced, and new methods had to be developed for reducing and working many of them. To mention only two—tungsten, which is invaluable for its use in high-speed tools, and aluminium, which is one of the most widely distributed metals, yet also one of the most difficult to reduce from its ores.

This rapid advance had been continued with increasing momentum during the present century. Almost all the metals and some of the non-metallic elements are now employed in the manufacture of alloys, the number of which in daily use is legion. One of the most remarkable and one of the latest to come into use is beryllium. This metal, alloyed with copper to the extent of about 2·5%, greatly increases the tensile strength. A new class of alloy, of which that just mentioned is one, has been introduced during the present century, the so-called age-hardening alloys. In 1911 Wilm discovered duralumin, an alloy of aluminium, copper, and magnesium. This alloy was found to have the remarkable property of increasing in hardness after suitable heat-treatment, and ageing at room temperature. This was the forerunner of a series of alloys, aluminium being the principal constituent, having similar properties. The heavy metals have since been found to produce alloys which behave in a like manner, the most notable examples being copper-beryllium and copper-nickel-aluminium.

The development of processes for the working of metals has also made rapid strides. The extrusion press has been in use for a considerable time, but lately it has been found possible to extrude alloys hitherto considered not amenable to this process. The electric furnace has been used for some time for melting, chiefly copper, but its use has been greatly extended since the introduction of the induction furnace. Great progress has been made in the provision of facilities for heat-treatment. The extension of the continuous furnace and the introduction of controlled atmospheres have contributed, while the developments in rolling mills and power presses are such as to make those in use only 20 years ago appear antiquated. In the casting of metals, the centrifugal method is of comparatively recent origin, but the most remarkable change in this direction has been the introduction of continuous casting. This process is still in the experimental state, but there is little doubt that it will be in fairly common use in the not far distant future. It is interesting to note that in 1846 Henry Bessemer took out a patent for such a method for making tinfoil and sheet lead. This was not worked commercially, but it provides a further illustration of the fact that many years often elapse from the birth of an idea to its successful application.

Industrial Lighting, Fittings and Accessories

With the present necessity for the complete screening of factory windows and the consequent lengthening of the hours during which work is carried on by artificial light, the question of adequate illumination in factories is becoming more and more important. The influence of good artificial lighting on the welfare of employees is well known, but it is not always realised that it can enable production to be even greater and wastage less than during the hours of daylight.

The essentials of industrial lighting are the provision of correctly designed equipment and its correct application. Modern equipment, both for general lighting and local lighting, is fully described in the new edition of G.E.C. Section F (4)—"Industrial Lighting Fittings and Accessories" and copies of this publication are available on application to General Electric Co., Ltd., Magnet House,

Business Notes and News

Iron and Steel Control Orders

The Minister of Supply has issued a Direction (No. 2), dated December 22, 1939, under the Control of Iron and Steel (No. 4) Order, 1939, to come into operation as from January 1, 1940.

The new Direction supersedes the Direction (No. 1) issued at the same time as the No. 4 Order. The main features of the new Direction are that the exemption of pre-war contracts from the requirement of a licence disappears, and in future deliveries under such contracts will be subject to the licensing provisions of the Order, and, except in the case of departments of the United Kingdom Government, the existing exemptions from licence have been restricted to purchasers of materials for use in the United Kingdom.

In addition, purchases of home iron ore, pyrites ash, burnt pyrites residues and boot and shoe grindery for use in the United Kingdom have been exempted from licence. Amendments have also been made in the provision for sale and purchase of small quantities of material without a licence. Eight additional related price schedules have been deposited.

Non-ferrous Metal Control

The Minister of Supply has issued the Control of Non-Ferrous Metals (No. 5) Order, which came into force on December 18. This Order brings together in one document, with some amendments, the operative provisions of the four previous non-ferrous metals Orders, which are now repealed. The most important feature of the new Order is the new scale of maximum prices fixed for copper, lead and zinc, and the consequential increases in the maximum prices of certain zinc products and varieties of non-ferrous scrap. The Order also sets out the circumstances in which the maximum prices may be varied for delivery in small lots, special shapes and sizes, etc., and empowers the Minister by special or general directions to prescribe what these variations shall be. Direction No. 1 issued with the Order fixes a scale of premiums for certain shapes and sizes of copper, and provides for a discount in the case of copper cathodes.

India Recovers Titanium Oxide from Mud Residue of Bauxite

The Industrial Research Bureau of the Indian Stores Department recently published a report concerning the recovery of titanium oxide from the mud residue of Indian bauxite utilised in the manufacture of alumina-ferric. It is stated in the report that Indian bauxite contains from 9% to 12% of titanium—a material which was never recovered previous to the development of the process. The recovered titanium dioxide is said to be from 98% to 99% pure, with only a trace of iron. Based on the experimental process, the cost of producing titanium oxide is 35 rupees per hundredweight, as compared with the domestic market price of titanium oxide of 56 rupees per hundredweight.

Institute of Marine Engineers: Lloyd's Register Scholarship

The General Committee of Lloyd's Register of Shipping offers a scholarship, valued at £100 per annum and tenable for three years, to be awarded on the results of the Studentship Examination of the Institute of Marine Engineers in May next. The scholarship is intended to assist marine engineering students to take an advanced course of instruction in engineering subjects. The age limit is 18 years to 23 years. The closing date for entries is April 8, 1940.

Further particulars, entrance forms, and copies of previous papers may be obtained on application to the Secretary of the Institute of Marine Engineers, 73, Amersham Road, High Wycombe, Bucks. The entrance form for the scholarship is distinct from the entrance form for the Studentship Examination, and a candidate for the Studentship Examination who wishes also to compete for the scholarship must complete and return both forms by the dates specified.

The Empire's Largest Forging

The forging of large steel products has made great progress in recent years, particularly for the manufacture of boiler drums and large cylindrical vessels for chemical and oil engineering processes. These forgings have involved complex investigations to determine correct methods of design, the most suitable material for the particular purpose and the proper technique to employ in forging the required shapes. The large size of forgings now made is sufficient in itself to make the production of such vessels a matter of note from an engineering point of view; this is especially true of a forging recently made at the Atlas Works of Thos. Firth and John Brown Ltd., which is claimed to be the largest ever produced in the British Empire.

The weight of ingot exceeded 200 tons, and owing to its enormous size, special precautions were necessary at every stage of production, both as regards the casting of the ingot and the forging to shape. The accompanying illustration shows the forging, under the tremendous pressure of the Firth-Brown press, gradually taking shape. Ingots ranging in size from a few hundredweights up to more than 200 tons are cast regularly at the Atlas Works, but that used in the forging illustrated is the largest of its type yet produced.

Forging a pressure vessel from the British Empire's largest ingot.

South African Iron and Steel Corporation Extensions to Plant

In connection with extensions to the steel-melting plant at the Iscor Works of the South African Iron and Steel Corporation, a contract has been placed with Messrs. Duncan Stewart and Co., Ltd., of Glasgow, a subsidiary of the Davy and United Engineering Co., Ltd., for a new Bessemer plant. The new plant will comprise a 750-ton inactive mixer, two 25-ton acid Bessemer converters, a turbo-blower, bottom-making plant, together with the auxiliary equipment and additional buildings. The Bessemer plant will operate with the present open-hearth furnaces on the duplex system.

Goods for use in Scientific Research

On September 8 the Treasury announced the suspension for the time being of licences issued under Section 8 of the Finance Act, 1936. The Treasury now give notice that they will consider applications for licences to import, free of duty, good intended to be used in scientific research.

Such applications, which should be addressed to the Secretary, H.M. Treasury, Whitehall, London, S.W. 1, must be made on behalf of educational institutions, hospitals or recognised scientific laboratories (including laboratories maintained by industrial organisations or consultants), and must be accompanied by a written statement by the responsible professor or director.

All applications must be made before the delivery of the goods to the importer, and, if a licence is necessary, the goods should not be shipped until a licence is obtained from the Import Licensing Department of the Board of Trade, 25, Southampton Buildings, Chancery Lane, London, W.C. 2.

MARKET PRICES

ALUMINIUM.

Ingots	£110	0	0

ANTIMONY.

English	£95	0	0
Foreign	76	10	0

BRASS.

Solid Drawn Tubes	lb.	£0	1	1¼
Brazed Tubes	,,	0	1	3¼
Rods Drawn	,,	0	0	11
Wire	,,	0	0	10½
*Extruded Brass Bars	,,	0	0	7½

COPPER.

Standard Cash	£44	5	0
Electrolytic	62	0	0
Best Selected	60	10	0
Tough	61	5	0
Sheets	96	10	0
Wire Bars	65	10	0
Ingot Bars	65	10	0
Solid Drawn Tubes	lb.	0	1	1½
Brazed Tubes	,,	0	1	1½

FERRO ALLOYS.

‡Tungsten Metal ° Powder, nominal	lb.	£0	4	5½
‡Ferro Tungsten ° nominal	,,	0	4	4
Ferro Molybdenum ° ,,	...		5	7
Ferro Chrome, 60-70% Chr. Basis 60% Chr. 2-ton lots or up.				
NOMINAL 2–4% Carbon, scale 15/– per unit	ton	45	5	0
NOMINAL 4–6% Carbon, scale 12/6 per unit	,,	39	10	0
NOMINAL 6–8% Carbon, scale 12/6 per unit	,,	38	10	0
NOMINAL 8–10% Carbon, scale 12/6 per unit	,,	38	10	0
§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch. Guar. max. 2% Carbon, scale 18/6 per unit	,,	58	0	0
Guar. max. 1% Carbon, scale 19/6 per unit	,,	60	0	0
§Guar. max. 0·5% Carbon, scale 20/– per unit	,,	71	0	0
‡Manganese Metal 97–98% Mn	lb.	1/5½ to 1/9		
‡Metallic Chromium	,,	3/5½ to 3/7½		
§Ferro-Vanadium 50–55%	,,	0	14	0
§Spiegel, 18–20%	ton	12	2	6
Ferro Silicon—				
Basis 10%, scale 3/– per unit nominal	ton	15	0	0
20/30% basis 25%, scale 3/6 per unit	,,	15	10	0
45/50% basis 45%, scale 5/– per unit	,,	19	0	0
70/80% basis 75%, scale 7/– per unit	,,	29	10	0
90/95% basis 90%, scale 10/– per unit	,,	40	0	0
§Silico Manganese 65/75% Mn, basis 65% Mn	,,	26	0	0
§Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	7½
Ferro Phosphorus, 20–25%	ton	35	0	0
§Ferro-Molybdenum, Molyte	lb.	0	5	3
§Calcium Molybdate	,,	0	5	0

FUELS.

Foundry Coke—			
S. Wales	£1	18	0
Scotland	1	15	0
Durham	1	17	0
Furnace Coke—			
Scotland	1	9	0
S. Wales	1	7	6
Durham	1	9	2

GUN METAL.

*Admiralty Gunmetal Ingots (88 : 10 : 2)		£94	0	0
*Commercial Ingots		80	0	0
*Gunmetal Bars, Tank brand, 1 in. dia. and upwards	lb.	0	1	1½
*Cored Bars	,,	0	1	3½

MANUFACTURED IRON.

Scotland—			
Crown Bars	£12	15	0
N.E. Coast—			
Rivets		—	
Best Bars	13	5	0
Crown Bars	12	18	0
Lancashire—			
Crown Bars	12	15	0
Hoops	13	11	0
Midlands—			
Crown Bars	12	15	0
Marked Bars	15	15	0
Unmarked Bars		—	
Nut and Bolt Bars	11	0	0
Gas Strip	13	12	0
S. Yorks.—			
Best Bars	12	5	0
Hoops	13	12	6

PHOSPHOR BRONZE.

*Bars, "Tank" brand, 1 in. dia. and upwards—Solid	lb.	£0	1	1¼
*Cored Bars	,,	0	1	3½
†Strip	,,	0	1	1½
†Sheet to 10 W.G.	,,	0	1	1¾
†Wire	,,	0	1	3½
†Rods	,,	0	1	3½
†Tubes	,,	0	1	9
†Castings	,,	0	1	3

†10% Phos. Cop. £30 above B.S.
†15% Phos. Cop. £35 above B.S.
†Phos. Tin (5%) £30 above English Ingots.

PIG IRON.

Scotland—			
Hæmatite M/Nos.	£6	4	6
Foundry No. 1	5	12	0
,, No. 3	5	9	6
N.E. Coast—			
Hæmatite No. 1	6	4	6
Foundry No. 1	5	11	0
,, No. 3	5	8	0
,, No. 4		—	
Silicon Iron		—	
Forge		—	
Midlands—			
N. Staffs. Forge No. 4		—	
,, Foundry No. 3	5	10	0
Northants—			
Foundry No. 1	5	11	6
Forge No. 4		—	
Foundry No. 3	5	7	6
Derbyshire Forge	5	0	0
,, Foundry No. 1	5	13	0
,, Foundry No. 3	5	10	0
West Coast Hæmatite	6	4	6
East ,, ,,	6	4	6

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,, Wire	55	10	0
Brass	47	0	0
Gun Metal	72	0	0
Zinc	10	0	0
Aluminium Cuttings	72	0	0
Lead	11	10	0
Heavy Steel—			
S. Wales	3	0	3
Scotland	2	19	0
Cleveland	3	1	0
Cast Iron—			
Midlands	3	7	0
S. Wales	3	7	9
Cleveland	3	6	6
Steel Turnings—			
Cleveland	2	7	0
Midlands	2	0	3
Cast Iron Borings—			
Cleveland	2	0	0
Scotland	2	0	0

SPELTER.

G.O.B. Official	£25	15	0
Hard		—	
English	26	10	0
Empire	26	10	0
Re-melted	16	10	0

STEEL.

Ship, Bridge and Tank Plates—			
Scotland	£11	10	6
North-East Coast	11	10	6
Midlands	11	13	0
Boiler Plates (Land) Scotland	11	10	6
,, ,, (Marine) ,,		—	
,, ,, (Land) N.E. Coast	11	10	6
,, ,, (Marine) ,,		—	
Angles, Scotland	11	8	0
,, North-East Coast	11	8	0
,, Midlands	11	8	0
Joists	11	8	0
Heavy Rails	10	3	0
Fishplates	14	10	0
Light Rails	12	2	6
Sheffield—			
Siemens Acid Billets	11	17	6
Hard Basic	10	7	6
Medium Basic	10	5	0
Soft Basic	10	0	0
Hoops	13	11	0
Manchester—			
Hoops	13	11	0
Scotland, Sheets 24 B.G.	16	2	6

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Round and Squares, 3 in.	,,	0	0	4
Flats under 1 in. × ⅜ in.	,,	0	0	3
,, ½ in. × ¼ in.	,,	0	1	0

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English	246	15	0
Tin Plates I.C. 20 × 14 box	£1 11 0/£1 12		0

ZINC.

English Sheets	£30	12	6
Zinc Boiler Plates	28	12	6
Battery Plates		—	
Boiler Plates		—	

LEAD.

Soft Foreign	£25	0	0
Empire	25	0	0

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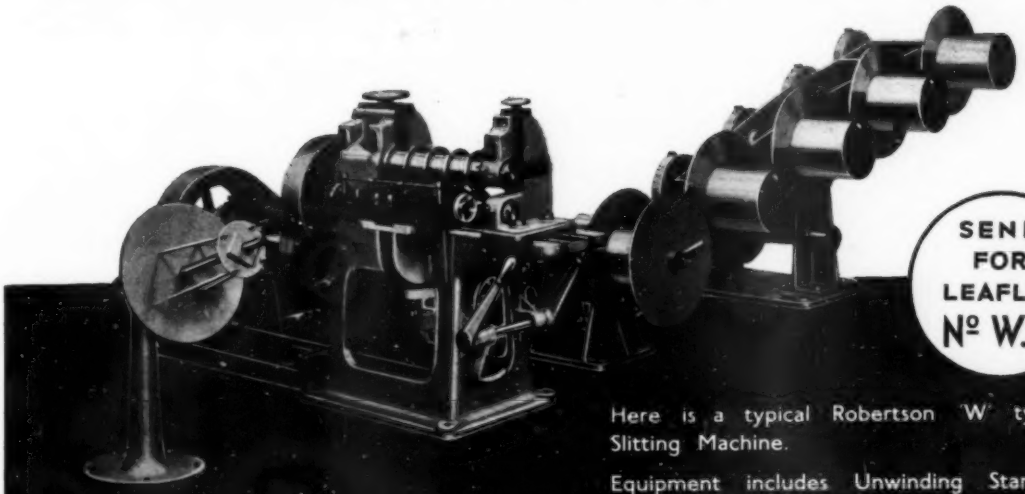

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